D2

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 716 468 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 158(3) EPC

(43) Date of publication:
12.06.1996 Bulletin 1996/24

(21) Application number: 94908501.3

(22) Date of filing: 07.03.1994

(51) Int. Cl.[6]: H01P 3/18, H01P 3/06, H01P 3/08, H01P 3/12, H01P 7/08, H01P 1/203, H01P 1/20

(86) International application number:
PCT/JP94/00357

(87) International publication number:
WO 95/06336 (02.03.1995 Gazette 1995/10)

(84) Designated Contracting States:
DE FR GB IT SE

(30) Priority: 27.08.1993 JP 212630/93

(71) Applicant: MURATA MANUFACTURING CO., LTD.
Nagaokakyo-shi, Kyoto 617 (JP)

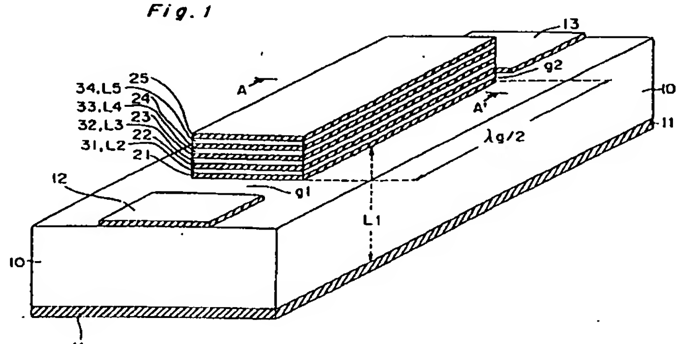
(72) Inventors:
- ISHIKAWA, Youhei
Murata Manufacturing Co., Ltd.
Nagaokakyo-shi Kyoto 617 (JP)
- HIDAKA, Seiji
Murata Manufacturing Co., Ltd.
Nagaokakyo-shi Kyoto 617 (JP)

(74) Representative: Herrmann-Trentepohl, Werner, Dipl.-Ing. et al
Patentanwälte Herrmann-Trentepohl,
Kirschner, Grosse, Bockhorni & Partner
Forstenrieder Allee 59
81476 München (DE)

(54) THIN-FILM MULTILAYER ELECTRODE OF HIGH FREQUENCY ELECTROMAGNETIC FIELD COUPLING

(57) A plurality of TEM mode transmission lines (L2-L5) are structured by pairs of thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) which sandwich thin film dielectrics (31 to 34) by alternately stacking the thin film conductor (21 to 25) and the thin film dielectric (31 to 34). The phase velocities of TEM mode waves which are propagated at least by two of the transmission lines (L2 to L5) are substantially equal to each other. The thickness of each of the thin film conductors (21 to 25) is smaller than the skin depth of the frequency used so that the electromagnetic fields of at least two TEM mode transmission lines among the TEM mode transmission lines (L2 to L5) are coupled to each other. In this way, the skin depth can be increased effectively. The conductor loss and the surface resistance can be reduced significantly as compared to those of the conventional electrode. By use of this electrode, a transmission line, a resonator, a filter, and a high frequency device are structured.

Fig. 1



EP 0 716 468 A1

Description

TECHNICAL FIELD

The present invention relates to a high frequency electromagnetic field coupled type thin film multilayered electrode used in high frequency bands of microwaves, semi-millimeter waves, or millimeter waves, and relates to a high frequency transmission line using the thin film multilayered electrode, a high frequency resonator using the thin film multilayered transmission line, a high frequency filter comprising the high frequency resonator, and a high frequency device comprising the thin film multilayered electrode.

BACKGROUND ART

With recent years' downsizing of electronic components, downsizing of devices has been implemented by using high dielectric materials even in high frequency bands of microwaves, semi-millimeter waves, or millimeter waves. For implementation of downsizing of a device, when the shape of the device is reduced into a similar shape while the dielectric constant thereof is increased, there is such a problem that in principle, an energy loss increase in inverse proportion to the cube root of its volume.

The energy loss of high frequency devices can be classified roughly into a conductor loss due to the skin effect and a dielectric loss due to the dielectric material thereof. Dielectric materials that have been developed into practical use in recent years include those having a low loss characteristic even in when they have their high dielectric constant, and therefore, the conductor loss rather than dielectric loss is predominant in the no-loaded Q of their circuits. As shown in FIG. 11, a high frequency current concentrates on the conductor surface due to the skin effect, so that the closer to the conductor surface the position is, the more the surface resistance (also referred to as a skin resistance) increases, and this leads to an increased conductor loss (Joule loss).

In view of these circumstances, an improved symmetrical strip line resonator (hereinafter, referred to as a conventional resonator) which is effectively reduced in conductor loss enough to obtain a high no-loaded Q has been proposed in the Japanese Patent Laid-Open Publication No. HEISEI 4 (1992)-43703. The conventional resonator is a symmetrical strip line resonator in which a resonator circuit is made up of symmetrical strip lines having a strip conductor disposed between a pair of earth conductors which are oppositely positioned a predetermined distance away from each other with a dielectric interposed therebetween, wherein the symmetrical strip line resonator is characterized in that a plurality of sheets of strip conductors is disPosed between the pair of earth conductors in parallel the pair of earth conductors so that the plurality of sheets of strip conductors are multilayered so as to be spaced from each other at a predetermined interval with the dielectric interposed therebetween.

The publication which discloses the above-mentioned conventional resonator also discloses the followings:

(a) it is preferably that the respective strip conductors are formed so as to have a thickness three times as thick as or more than the skin depth in order to effectively suppress the conductor loss; that is, in the strip conductors, the skin portion through which a high frequency current of microwave band flows is increased so that the effective sectional area in the strip conductors is increased;
(b) a pair of strip conductors are made to conduct with each other at their one end via a through hole while they are made to conduct with each other also at another end via a through hole; and
(c) an electric field distribution of the resonator is formed so that the electric field is directed from each of the strip conductors toward the earth conductors as shown in FIG. 3 of the publication.

However, since it has the above-mentioned structure (a), there is such a problem that it is difficult to reduce the size and weight thereof, and the resonator has a relatively small reduction rate in conductor loss as well as a relatively small no-loaded Q.

Accordingly, the object of the present invention is to dissolve the above-mentioned problems, and is to provide a high frequency electrode which can remarkably reduce the conductor loss as compared with that of the conventional counterpart, and yet which can reduce the size and the weight of the embodied product of the present invention, and to provide a high frequency transmission line, a high frequency resonator, a high frequency filter, and a high frequency device.

DISCLOSURE OF THE INVENTION

The present inventor provides a high frequency electromagnetic field coupled type thin film multilayered electrode, a thin film multilayered transmission line and the like, capable of remarkably reducing the conductor loss by suppressing the skin effect with a structure completely different from that of the conventional resonator, i.e., with a thin film multilayered

electrode formed by alternately stacking a thin film conductor and a thin film dielectric, each thin film conductor having a film thickness smaller than a skin depth δo of a frequency which is used.

A high frequency electromagnetic field coupled type thin film multilayered electrode according to the present invention is a thin film multilayered electrode characterized in that

thin film conductors (21-25) and thin film dielectrics (31-34) are alternately smacked so that a plurality of TEM mode transmission lines (L2-L5) are multilayered, each of the TEM mode transmission lines (L2-L5) comprising a pair of the thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of the thin film dielectrics (31-34) is sandwiched,

wherein phase velocities of TEM waves which propagate through at least two of the plurality of TEM mode transmission lines (L2-L5) are made substantially equal to each other and a film thickness of each of the thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used, so that electromagnetic fields of at least two of the plurality of TEM mode transmission lines (L2-L5) are coupled with each other. In this case, each of the thin film conductors (21-25) is preferably made of a superconducting material.

Further, a high frequency transmission line according to the present invention is a high frequency transmission line having at least one conductor, the conductor comprising a thin film multilayered electrode in which thin film conductors (21-25) and thin film dielectrics (31-34) are alternately stacked so that a plurality of TEM mode transmission lines (L2-L5) are multilayered, each of the TEM mode transmission lines (L2-L5) comprising a pair of the thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of the thin film dielectrics (31-34) is sandwiched,

wherein phase velocities of TEM waves which propagate through at least two of the plurality of TEM mode transmission lines (L2-L5) are made substantially equal to each other, and a film thickness of each of the thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used, so that electromagnetic fields of at least two of the plurality of TEM mode transmission lines (L2-L5) are coupled with each other. In this case, the high frequency transmission line is implemented by, for example, a waveguide.

Further, a high frequency transmission line according to the present invention is a high frequency transmission line comprising:

a first transmission line (L1); and

at least one TEM mode second transmission line (L2-L5) in which a thin film conductor (21-25) and a thin film dielectric (31-34) are alternately stacked so that the TEM mode second transmission line (L2-L5) comprises a pair of the thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of the thin film dielectrics (31-34) is sandwiched,

wherein a phase velocity of an electromagnetic wave which propagates through the first transmission line (L1) and a phase velocity of a TEM wave which propagates through at least one of the second transmission line (L2-L5) are made substantially equal to each other, and a film thickness of the thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used so that an electromagnetic field of the first transmission line (L1) and an electromagnetic field of at least one of the second transmission line (L2-L5) are coupled with each other.

In the above-mentioned high frequency transmission line, an effective dielectric constant of the thin film dielectric (31-34) constituting the second transmission line (L2-L5) is preferably made smaller than an effective dielectric constant of the dielectric constituting the first transmission line (L1). By this arrangement, the phase velocity of the electromagnetic wave which propagates through the first transmission line (L1) and the phase velocity of the TEM wave which propagates through at least one of the second transmission line (L2-L5) can be substantially made equal to each other.

In the above-mentioned high frequency transmission line, the thickness of the thin film dielectric (31-34) constituting the second transmission line (L2-L5) is made smaller than the thickness of the dielectric constituting the first transmission line (L1). By this arrangement, a time required for a film forming process of the second transmission line (L2-L5) can be reduced, and a low-impedance system transmission line having an impedance lower than that of the second transmission line (L2-L5) can be constituted, thereby allowing a reduced transmission loss to be achieved.

In the above-mentioned high frequency transmission line, the high frequency transmission line (L1) is preferably a microstrip line. In the present case, the microstrip line is so constructed that the second transmission line (L2-L5) is formed as a microstrip conductor on a first surface of a dielectric substrate (10), while an earth conductor (11) is formed on a second surface of the dielectric substrate (10). Alternatively, the microstrip line is so constructed that the second transmission line (L2-L5) is formed as a microstrip conductor on the first surface of the dielectric substrate (10), while another one of second transmission line (L2-L5) is formed as an earth conductor on the second surface of the dielectric substrate (10). Further, the high frequency transmission line is preferably a strip line. Still further, the high frequency transmission line is preferably a coaxial line. Yet further, in the above-mentioned high frequency transmission line, the thin film conductors (21-25) is made of a superconducting material.

A high frequency resonator according to the present invention comprises the above-mentioned high frequency transmission line having predetermined dimensions. In this case, the high frequency transmission line preferably has a length equal to a quarter of a guide wavelength of a signal transmitted through the high frequency transmission line, in a direction in which the signal is transmitted.

Further, a high frequency filter according to the present invention comprises the high frequency resonator having a predetermined length, an input terminal (12) for inputting a high frequency signal to the high frequency resonator, and an output terminal (13) for outputting a high frequency signal from the high frequency resonator.

Further, a high frequency band-elimination filter according to the present invention comprises a transmission line (L10) for inputting a high frequency signal at one end thereof and outputting the high frequency signal at another end thereof, and a high frequency resonator to be coupled with the transmission line (L10). In the high frequency resonator, the high frequency transmission line preferably has a length equal to a quarter or a half of a guide wavelength of a signal transmitted through the high frequency transmission line, in a direction in which the signal is transmitted.

Still further, a dielectric resonator according to the present invention is a dielectric resonator comprising a resonator casing (77) including a conductor and a dielectric (76) which has a predetermined configuration and is arranged within the resonator casing (77), wherein the conductor is implemented by the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode.

Further, a high frequency filter according to the present invention comprises the dielectric resonator, an input terminal for inputting a high frequency signal to the dielectric resonator, the input terminal being electromagnetically coupled with the dielectric resonator, and an output terminal for outputting the high frequency signal from the dielectric resonator, the output terminal being electromagnetically coupled with the dielectric resonator.

Further, a high frequency device according to the present invention is a high frequency device which comprises an electrode and performs a predetermined high frequency operation, the electrode having the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode.

In the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode, when the TEM mode transmission line (L2-L5) is excited by a high frequency signal, each of the thin film conductor (21-25) transmits a part of high frequency power incident thereon via an adjacent thin film dielectric (31-34) to a thin film conductor (21-25) adjacent in a different direction, while reflecting a part of the high frequency power onto the adjacent thin film conductor (21-25) via the thin film dielectric (31-34). Within the thin film dielectrics (31-34) each of which is sandwiched by two adjacent thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25), the reflection wave and transmission wave are resonating, while oppositely directed and facing two high frequency currents flow in the vicinity of the upper and lower surfaces of the conductor thin films (21-25). Therefore, since the film thickness of each of the thin film conductors (21-25) is smaller than a skin depth δo, the oppositely directed and facing two high frequency currents interfere with each other, and are canceled by each other except for a remaining part thereof. In this way, in the high frequency electromagnetic field coupled type thin film multilayered electrode, a resonance energy or a transmission energy of adjacent thin film dielectrics (31-34) is coupled with each other via the thin film conductors (21-25). On the other hand, the thin film dielectrics (31-34) have a displacement current generated by an electromagnetic field, this causing a high frequency current to be generated to the surface of their adjacent thin film conductors (21-25).

Furthermore, since phase velocities of TEM waves which propagate through at least two of the plurality of TEM mode transmission lines (L2-L5) are made substantially equal to one another, high frequency currents flowing through the thin film conductors (21-25) are substantially in phase with each other. As a result of this, the high frequency currents flowing in the thin film conductors (21-25) in phase increase the effective skin depth δo. Therefore, when excitation is effected by a high frequency signal, an electromagnetic energy of the high frequency is transferred to an adjacent transmission line (L2-L5) through an electromagnetic coupling of the adjacent TEM mode transmission lines (L2-L5) whose electromagnetic fields are coupled, while the electromagnetic energy propagates in the longitudinal direction of the transmission lines (L2-L5). In this case, the electromagnetic energy of high frequency propagates in the longitudinal direction of the lines through electromagnetically coupled transmission lines (L2-L5), so that the energy propagates with an effectively increased skin depth δo, that is, a decreased surface resistance R_S.

Also, in the high frequency transmission line, the conductor is implemented by the high frequency electromagnetic field coupled type thin film multilayered electrode, so that the conductor has a decreased surface resistance R_S in a manner similar to that of the above-mentioned electrode. Accordingly, the high frequency transmission line is given as a transmission line having an extremely small transmission loss.

Further, in the above-mentioned further high frequency transmission line, the second transmission line (L2-L5) is formed of a pair of thin film conductors (21-25) sandwiching a thin film dielectric (31-34) by alternately stacking thin film conductors (21-25) and thin film dielectrics (31-34),

wherein a phase velocity of an electromagnetic wave propagating through the first transmission line (L1) and a phase velocity of a TEM wave propagating through at least one of the second transmission line (L2-L5) are made substantially equal to each other, and a thickness of each of the thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used, so that an electromagnetic field of the first transmission line (L1) and an electromagnetic field of at least one of the second transmission line (L2-L5) are coupled with each other. In the high frequency transmission line, between the first transmission line (L1) and at least one of the second transmission line (L2-L5), there occurs an action similar to that of the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode. That is, since high frequency electromagnetic field energy propagates in the longitudinal direction of the line via the second transmission lines (L2-L5) electromagnetically coupled with each other, the energy propagates

with an effectively greater skin depth δo, i.e. a smaller surface resistance R_S. Therefore, the high frequency transmission lines are those having an extremely small transmission loss.

Still further, the above-mentioned high frequency resonator is provided with the above-mentioned high frequency transmission lines having predetermined dimensions. Accordingly, the resonator has an extremely small transmission loss, and therefore, a resonator having an extremely large no-loaded Q is constituted.

In the above-mentioned dielectric resonator, the conductor of the resonator casing (77) is implemented by the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode, and therefore, a dielectric resonator having an extremely large no-loaded Q is constituted.

Further, the above-mentioned high frequency filter is provided with the high frequency resonator having the predetermined length, thereby constituting a band-pass or band-elimination filter each having an extremely large no-loaded Q.

Further, in the high frequency band-elimination filter, the above-mentioned high frequency resonator having the predetermined length operates as a trap circuit, thereby constituting a band-elimination filter having an extremely large no-loaded Q.

Yet further, in the high frequency device, the electrode comprises the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode, thereby constituting a high frequency device having an extremely small conductor loss.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a filter using a half-wavelength line type resonator using an electromagnetic field coupled type thin film multilayered transmission line which is a first embodiment according to the present invention.

FIG. 2 is a longitudinal sectional view taken along a line A - A' of the half-wavelength line type resonator of FIG. 1.

FIG. 3 is a schematic longitudinal sectional view of the half-wavelength line type resonator of FIG. 1 taken in the longitudinal direction thereof, and a circuit diagram of a circuit connected thereto.

FIG. 4 is a circuit diagram of an equivalent circuit of the half-wavelength line type resonator of FIG. 1.

FIG. 5 is a graph showing a frequency characteristic of a transmission coefficient S_{21}, which is a simulation result of the half-wavelength line type resonator of FIG. 1.

FIG. 6 is a graph showing frequency characteristics of relative amplitudes of currents flowing through the thin film conductors 21 to 25, which are simulation results of the half-wavelength line type resonator of FIG. 1.

FIG. 7 is a graph showing frequency characteristics of phase differences of currents flowing through the thin film conductors 21 to 25, which are simulation results of the half-wavelength line type resonator of FIG. 1.

FIG. 8 is a graph showing frequency characteristics of transmission coefficients S_{21} with a number n of multilayered layers used as a parameter, which are simulation results of the half-wavelength line type resonator of FIG. 1.

FIG. 9 is a graph showing normalized conductor film thickness $\Delta\xi/\delta o$ to Q increasing rate characteristics with the number n of multilayered layers used as a parameter, which are simulation results of the half-wavelength line type resonator of FIG. 1.

FIG. 10 is a graph showing optimum design conditions for equalizing phase velocities for an effective dielectric constant ratio $\varepsilon_s/\varepsilon_m$ to normalized dielectric film thickness $\Delta x_s/\delta o$ characteristic with the number n of multilayered layers used as a parameter, which is a simulation result of the half-wavelength line type resonator of FIG. 1.

FIG. 11 shows a current density distribution of the conductors through which a high frequency wave has been transmitted.

FIG. 12 shows an ideal current density distribution of the thin film multilayered transmission line of FIG. 1 through which a high frequency wave has been transmitted.

FIG. 13 shows an actual current density distribution of the thin film multilayered transmission line of FIG. 1 through which a high frequency wave has been transmitted.

FIG. 14 is a flow chart showing a flow for determining optimum parameters in the half-wavelength line type resonator of FIG. 1.

FIG. 15 is a flow chart showing a flow for determining a minimized surface resistance in the half-wavelength line type resonator of FIG. 1.

FIG. 16 is a circuit diagram showing an equivalent circuit of a half-wavelength line type resonator filter using an electromagnetic field coupled type thin film multilayered transmission line which is a second embodiment according to the present invention.

FIG. 17 is a graph showing frequency characteristic of a transmission coefficient S_{21}, which is a simulation result of the half-wavelength line type resonator of FIG. 16.

FIG. 18 is a perspective view of a quarter-wavelength line type band-elimination filter using an electromagnetic field coupled type thin film multilayered transmission line which is a third embodiment according to the present invention.

FIG. 19 is a circuit diagram including an equivalent circuit of the quarter-wavelength line type band-elimination filter of FIG. 18.

FIG. 20 shows various kinds of microwave lines and waveguides using an electromagnetic field coupled type thin film multilayered electrode according to the present invention,

wherein FIG. 20 (a) is a perspective view of a microstrip line using an electromagnetic field coupled type thin film multilayered electrode according to the present invention; FIG. 20 (b) is a perspective view of a strip line using an electromagnetic field coupled type thin film multilayered electrode according to the present invention; FIG. 20 (c) is a perspective view of a coaxial line using an electromagnetic field coupled type thin film multilayered electrode according to the present invention; and FIG. 20 (d) is a longitudinal sectional view of a TM_{01} mode circular waveguide using an electromagnetic field coupled type thin film multilayered electrode according to the present invention.

FIG. 21 is a schematic longitudinal sectional view of the half-wavelength line type resonator of FIG. 1 in the longitudinal direction, showing an operation thereof.

FIG. 22 is a circuit diagram showing an equivalent circuit of a four-terminal circuit in FIG. 4.

FIG. 23 is a perspective view showing a TM_{110} double mode type dielectric resonator of a modified embodiment.

FIG. 24 is a longitudinal sectional view showing a $TM_{01\delta}$ mode type two-stage dielectric band-pass filter of a modified embodiment.

FIG. 25 is a graph showing an effective current value of a current flowing through each of the thin film conductors 21 to 25 and the earth conductor 11 relative to a distance of transmission in the case where a film thickness Δx_s of the thin film dielectrics 31 to 34 is made to be smaller in the thin film multilayered transmission line according to the present invention.

FIG. 26 is a graph showing an effective current value of a current flowing through each of the thin film conductors 21 to 25 and the earth conductor 11 relative to a distance of transmission in the case where the film thickness Δx_s of the thin film dielectrics 31 to 34 is made to be greater in the thin film multilayered transmission line according to the present invention.

FIG. 27 is a sectional view of a modified embodiment using a thin film multilayered transmission line as an earth conductor in the half-wavelength line type resonator using an electromagnetic field coupled type thin film multilayered transmission line which is a first embodiment of the present invention.

FIG. 28 is a graph showing a relative amplitude of a current flowing through each of the thin film conductors 21 to 25 and the earth conductor 11 relative to the distance of transmission of the half-wavelength line type resonator of FIG. 1.

BEST MODE FOR CARRYING OUT THE INVENTION

Embodiments of the present invention will be hereinafter described with reference to the accompanying drawings. It is noted that the same components are denoted by the same reference numerals in the accompanying drawings.

First Embodiment

FIG. 1 is a perspective view of a filter using a half-wavelength line type resonator using an electromagnetic field coupled type thin film multilayered transmission line which is a first embodiment according to the present invention, and FIG. 2 is a longitudinal sectional view of the half-wavelength line type resonator of FIG. 1 taken along a line A - A'.

The half-wavelength line type resonator of the first embodiment is characterized in using an electromagnetic field coupled type thin film multilayered transmission line using an electromagnetic field coupled type thin film multilayered electrode according to the present invention, which has a structure that thin film conductors 21 to 25 and thin film dielectrics 31 to 34 are alternately stacked or multilayered. In the electromagnetic field coupled type thin film multilayered transmission line, a TEM mode microstrip line (hereinafter, referred to as a main transmission line) L1 is made up of a thin film conductor 21, an earth conductor 11, and a dielectric substrate 10 sandwiched between the thin film conductor 21 and the earth conductor 11, while four TEM mode microstrip lines (hereinafter, referred to as sub-transmission lines) L2 to L5 are stacked or multilayered on the main transmission line L1, each sub-transmission line being made up in such a way that one thin film dielectric is sandwiched between a pair of thin film conductors. In FIG. 1 and the following drawings, reference numerals for the transmission lines are added behind "," (comma) to reference numerals of the dielectrics.

More specifically, the half-wavelength line type resonator is characterized in that:

(a) a film thickness Δx_s and a dielectric constant ε_s of each of the thin film dielectrics 31 to 34 are bet to predetermined values, respectively, so that the phase velocities of TEM waves which propagate through the respective transmission lines L1 to L5 are made substantially equal to each other; and

(b) a film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 is set to predetermined film thicknesses smaller than the skin depth δo of a frequency used, so that between the adjacent transmission lines L1 and L2, L2 and L3, L3 and L4, and L4 and L5, their electromagnetic fields are coupled with each other. By this arrangement, high frequency energy flowing through the main transmission line L1 is transferred to the sub-transmission lines L2 to

L5, so that a high frequency current substantially uniformly flows through the respective thin film conductors 21 to 25, and this leads to that the skin effect due to the high frequency is remarkably suppressed.

As shown in FIG. 1, on the dielectric substrate 10 having the earth conductor 11 formed over its entire rear surface, there is formed a strip-shaped thin film conductor 21 whose longitudinal length is $\lambda g/2$ (where λg is a guide wavelength). In this arrangement, the main transmission line L1 in the form of a microstrip line is made up of the thin film conductor 21, the earth conductor 11, and the dielectric substrate 10 sandwiched between the thin film conductor 21 and the earth conductor 11. Further, on the thin film conductor 21, there are formed the thin film dielectric 31, the thin film conductor 22, the thin film dielectric 32, the thin film conductor 23, the thin film dielectric 33, the thin film conductor 24, the thin film dielectric 34, and the thin film conductor 25 so as to be stacked in this order. In this case, the sub-transmission lines L2 to L5 are formed in the following way:

(a) the thin film dielectric 31 is sandwiched between a pair of thin film conductors 21 and 22, and this results in that the sub-transmission line L2 is made up;
(b) the thin film dielectric 32 is sandwiched between a pair of thin film conductors 22 and 23, and this results in that the sub-transmission line L3 is made up;
(c) the thin film dielectric 33 is sandwiched between a pair of thin film conductors 23 and 24, and this results in that the sub-transmission line L4 is made up; and
(d) the thin film dielectric 34 is sandwiched between a pair of thin film conductors 24 and 25, and this results in that the sub-transmission line L5 is made up.

It is noted that the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 and the film thickness Δx_s of each of the respective thin film dielectrics 31 to 34 are set as detailed later by using the flow for determining the optimum parameters of FIG. 12.

Further, on the dielectric substrate 10, an input-terminal conductor 12 is formed a predetermined gap g1 away from one longitudinal end of the thin film conductor 21 and close thereto enough to be electromagnetically coupled with each other, while an output-terminal conductor 13 is formed a predetermined gap g2 away from another longitudinal end of the thin film conductor 21 and close thereto enough to be electromagnetically coupled with each other. It is noted that in the first embodiment, the coupling between the input-terminal conductor 12 and one end of the thin film conductor 21 and the coupling between the output-terminal conductor 13 and another end of the thin film conductor 21 are both capacitive couplings.

In the present case, the dielectric substrate 10 is made of, for example, sapphire, which is an alumina single crystal, while the thin film dielectrics 31 to 34 are made of, for example, SiO_2. On the other hand, the earth conductor 11 and the thin film conductors 21 to 25 are made of a conductor such as Cu, Ag, or Au having an electric conductivity.

FIG. 2 shows electric field and magnetic field distributions in the half-wavelength line type resonator which is constructed as described above. FIG. 2 is a sectional view, however, in FIG. 2 the hatching of the dielectrics is omitted.

As seen from FIG. 2, the electric fields are distributed in a direction perpendicular to the surfaces of the thin film conductors 21 to 25 and identical to one another. On the other hand, the magnetic fields are distributed in a direction parallel to the surfaces of the thin film conductors 21 to 25 and identical to one another. From this fact, it can be seen that the electromagnetic fields of the respective transmission lines L1 to L5 are coupled with one another.

FIG. 3 is a schematic longitudinal sectional view of the half-wavelength line type resonator of FIG.1 in its longitudinal direction, and a circuit diagram of a circuit connected thereto, and FIG. 4 is a circuit diagram of an equivalent circuit of the half-wavelength line type resonator of FIG. 1.

As shown in FIG. 4, the main transmission line L1 comprises a distributed constant circuit comprised of LC unit distributed constant circuits connected in series and having inductors L11, L12, ..., L1n and capacitors C11, C12, ..., C1n. A signal generator Vsg for exciting the resonator Vsg and its internal resistance Rsg are connected to one end of the main transmission line L1 via an ideal transformer T11 having a turn ratio corresponding to the gap g1, while a load resistance R_L is connected to another end of the main transmission line L1 via an ideal transformer T12 having a turn ratio corresponding to the gap g2. It is noted that the turn ratio of all the following ideal transformers is 1 : 1. In the main transmission line L1, ideal transformers T111, T112, ..., T11n are inserted so as to be connected to the lower line in the figure between the respective unit distributed constant circuits, and the ideal transformers T111, T112, ..., T11n are grounded via four-terminal circuits F1, F2, ..., Fn, which comprise a distributed constant circuit including a loss resistance, and via ideal transformers T101, T102, ..., T10n, respectively.

It is noted that the four-terminal circuits (denoted by "F + number") which appear hereinbelow are equivalent circuits of the earth conductor 11 and the thin film conductors 21 to 25, and each of the four-terminal circuit comprises a distributed constant circuit including a loss resistance as shown in FIG. 22. More specifically, each of the four-terminal circuits comprises an equivalent circuit in which a plurality of unit circuits each comprising a unit conductance gdx, a unit capacitance cdx, and a unit inductance ldx are connected in series. In this case, the unit conductance gdx, the unit capacitance cdx, and the unit inductance ldx are represented by the following equations, respectively:

$$gdx = \sigma(\Delta y/dz)dx,$$

$$cdx = \varepsilon o(\Delta y/dz)dx, \text{ and}$$

$$ldx = \mu o(dz/\Delta y)dx,$$

where σ is an electric conductivity of the earth conductor 11 and the thin film conductors 21 to 25;

εo is a dielectric constant in vacuum;

μo is a permeability in vacuum;

dx is an infinitesimal length of the earth conductor 11 and the thin film conductors 21 to 25 in the direction of thickness thereof;

Δy is a line width; and

dz is an infinitesimal length in the direction of propagation.

The sub-transmission line L2 comprises a distributed constant circuit in which LC unit distributed constant circuits are connected in series and which has inductors L21, L22, ..., L2n and capacitors C21, C22, ..., C2n. An ideal transformer T21 whose primary turn is open is connected to one end of the sub-transmission line L2 while an ideal transformer T22 whose secondary turn is open is connected to another end of the sub-transmission line L2. Further, the sub-transmission lines L3, L4, and L5 are made up in the following way similar to that of the sub-transmission line L2. The sub-transmission line L3 comprises a distributed constant circuit in which LC unit distributed constant circuits are connected in series and which has inductors L31, L32, ..., L3n and capacitors C31, C32, ..., C3n. An ideal transformer T31 whose primary turn is open is connected to one end of the sub-transmission line L3, while an ideal transformer T32 whose secondary turn is open is connected to another end of the sub-transmission line L3. Also, the sub-transmission line L4 comprises a distributed constant circuit in which LC unit distributed constant circuits are connected in series and which has inductors L41, L42, ..., L4n and capacitors C41, C42, ..., C4n. An ideal transformer T41 whose primary turn is open is connected to one end of the sub-transmission line L4, while an ideal transformer T42 whose secondary turn is open is connected to another end of the sub-transmission line L4. Further, the sub-transmission line L5 comprises a distributed constant circuit in which LC unit distributed constant circuits are connected in series and which has inductors L51, L52, ..., L5n and capacitors C51, C52, ..., C5n. An ideal transformer T51 whose primary turn is open is connected to one end of the sub-transmission line L5, while an ideal transformer T52 whose secondary turn is open is connected to another end of the sub-transmission line L5.

An equivalent circuit within the thin film conductor 21 for connecting the adjacent transmission lines L1 and L2 to each other is made up in the following way. That is, in the main transmission line L1, ideal transformers T121, T122, ..., T12n are inserted so as to be connected to the upper line in the figure between the unit distributed constant circuits. The ideal transformers T121, T122, ..., T12n are connected respectively to ideal transformers T211, T212, ..., T21n inserted so as to be connected to the lower line in the figure between the unit distributed constant circuits of the sub-transmission line L2, respectively, via four-terminal circuits F11, F12, ..., F1n corresponding to the thin film conductor 21.

Also, an equivalent circuit within the thin film conductor 22 for connecting the adjacent transmission lines L2 and L3 to each other is made up in the following way. That is, in the sub-transmission line L2, ideal transformers T221, T222, ..., T22n are inserted so as to be connected to the upper line in the figure between the unit distributed constant circuits. The ideal transformers T221, T222, ..., T22n are connected respectively to ideal transformers T311, T312, ..., T31n inserted so as to be connected to the lower line in the figure between the unit distributed constant circuits of the sub-transmission line L3, respectively, via four-terminal circuits F21, F22, ..., F2n corresponding to the thin film conductor 22.

Further, an equivalent circuit within the thin film conductor 23 for connecting the adjacent transmission lines L3 and L4 to each other is made up in the following way. That is, in the sub-transmission line L3, ideal transformers T321, T322, ..., T32n are inserted so as to connected to the upper line in the figure between the unit distributed constant circuits. The ideal transformers T321, T322, ..., T32n are connected respectively to ideal transformers T411, T412, ..., T41n inserted so as to be connected to the lower line in the figure between the unit distributed constant circuits of the sub-transmission line L4, respectively, via four-terminal circuits F31, F32, ..., F3n corresponding to the thin film conductor 23.

Still further, an equivalent circuit within the thin film conductor 24 for connecting the adjacent transmission lines L4 and L5 to each other is made up in the following way. That is, in the sub-transmission line L4, ideal transformers T421, T422, ..., T42n are inserted so as to be connected to the upper line in the figure between the unit distributed constant circuits. The ideal transformers T421, T422, ..., T42n are connected respectively to ideal transformers T511, T512, ..., T51n inserted so as to be connected to the lower line in the figure between the unit distributed constant circuits of the sub-transmission line L5, respectively, via four-terminal circuits F41, F42, ..., F4n corresponding to the thin film conductor 24.

Further, an equivalent circuit corresponding to the electromagnetic field distribution formed from the thin film conductor 25 toward the space is made up in the following way. That is, in the sub-transmission line L5, ideal transformers T521, T522, ..., T52n are inserted so as to be connected to the upper line in the figure between the unit distributed constant circuits. The ideal transformers T521, T522, ..., T52n are connected respectively to load resistances R_{L1}, R_{L2},

..., R_{Ln}, respectively, via four-terminal circuits F51, F52, ..., F5n and ideal transformers T531, T532, ..., T53n corresponding to the thin film conductor 25.

Next, described below are a flow for determining the optimum parameters in the resonator of FIG. 1 and a flow for determining a minimized surface resistance Rs, with the use of the following parameters:

n : a number of multilayered layers,
ωo : a transmission (excitation) angular frequency which is used,
μo : a permeability in vacuum,
σ : an electric conductivity of each of the thin film conductors 21 to 25,
δo : a skin depth at a transmission angular frequency ωo,
ε_s : a dielectric constant of each of the thin film dielectrics 31 to 34 of the sub-transmission lines L2 to L5,
ε_m : a dielectric constant of the dielectric substrate 10 of the main transmission line L1,
Δx_s : a film thickness of each of the thin film dielectrics 31 to 34 of the sub-transmission lines L2 to L5,
Δx_m : a substrate thickness of the dielectric substrate 10 of the main transmission line L1,
$\Delta\xi$: a film thickness of each of the thin film conductors 21 to 25,
Δy : (a line width) = (a width of each of the thin film conductors 21 to 25) = (a width of each of the thin film dielectrics 31 to 34),
β_s : a phase constant of each of the sub-transmission lines L2 to L5, and
β_m : a phase constant of the main transmission line L1.

The recursion formula of a complex impedance Z on the transmission lines L1 to L5 normalized into dimensionless based on the equivalent circuit as shown in FIG. 4 can be represented by the following Equation (1a):

$$Zk = -jw + Z + [Y + (Z + Z_{k+1})^{-1}]^{-1}, \quad (1a)$$

$$k = 0, 1, 2, ..., n-1$$

where an n-th complex impedance Z_n is represented as follows:

$$Z_n = \sqrt{\left(\frac{\mu o}{\varepsilon o}\right) \cdot \sigma \delta o} \quad (1b)$$

In the above equations, the subscript k of the complex impedance Z shows a line number numbered in the increasing order from 0 for the main transmission line L1 toward the upper-layer sub-transmission lines L2 to L5. Also, the complex impedance Z and the complex admittance Y are defined respectively by functions represented each with a medium parameter ξ used as a parameter by the following Equation (2) and Equation (3):

$$Z = (1 + j) \cdot \tanh[(1 + j)/2 \cdot \xi] \quad (2), \text{ and}$$

$$Y = 1/(1 + j) \cdot \sinh[(1 + j) \cdot \xi] \quad (3).$$

Further, a structural parameter w and the medium parameter ξ are defined respectively by the following Equation (4) and Equation (5):

$$w = \{2\Delta x_s/\delta o\} \cdot (\varepsilon_m/\varepsilon_s - 1) \quad (4), \text{ and}$$

$$\xi = \Delta \xi/\delta o \quad (5)$$

where δo is a skin depth at a transmission angular frequency ωo and defined by the following Equation (6):

$$\delta o = \sqrt{\frac{2}{\omega o \mu o \sigma}} \quad (6)$$

Since the complex impedance Z_n can be given as a boundary condition of a vacuum layer as shown in the Equation (1b), a complex impedance Z_0 is defined as a two-parameter function of the structural parameter w and the medium parameter ξ by the following Equation (7):

$$Z_0 = Z_0 (w, \xi) \quad (7).$$

In the above Equation (7), when the real part of the complex impedance Z_0 is the minimum, the surface resistance R_s of the thin film multilayered transmission lines becomes the minimum. Accordingly, the structural parameter w and the medium parameter ξ obtained when the surface resistance R_s is the minimum are referred to as optimum set values, and are represented as w_{opt} and ξ_{opt}, respectively. In this case, the following Equation (8) holds:

$$R_s = \mathrm{Re}\,[Z_0(w_{opt}, \xi_{opt})]/\sigma\delta o \quad (8).$$

If the optimum values w_{opt} and ξ_{opt} are substituted into the above Equation (8), the dielectric film thickness Δx_s and the conductor film thickness $\Delta\xi$ of each of the sub-transmission lines L2 to L4 are determined, and then, the following Equations (9) and (10) are obtained:

$$\Delta x_s = w_{opt}\delta o/2 \cdot (\varepsilon_m/\varepsilon_s - 1)^{-1} \quad (9), \text{ and}$$

$$\Delta\xi = \xi_{opt}\delta o \quad (10).$$

Next, description is made hereinafter on a method for determining the optimum parameters w_{opt} and ξ_{opt} and the minimized surface resistance Rs in the half-wavelength line type resonator according to the present invention. In this case, it is assumed that a number n of multilayered layers, an electric conductivity σ of each of the thin film conductors 21 to 25, a skin depth δo, a dielectric constant ε_s of each of the thin film dielectrics 31 to 34, and a dielectric constant ε_m of the dielectric substrate 10 are previously given.

FIG. 14 is a flow chart showing a flow for determining the optimum parameters w_{opt} and ξ_{opt} in the half-wavelength line type resonator according to the present invention.

As shown in FIG. 14, at step S1, the n-layer recursion formula (1) is determined based on the predetermined number n of multilayered layers. Then, the following determinations are made based on the n-layer recursion formula.

At step S2, the optimum structural parameter w_{opt} is determined based on optimization for equalizing phase velocities β of TEM waves which propagate through the transmission lines L1 to L5. Then at step S3, the film thickness Δx_s of each of the thin film dielectrics 31 to 34 of the sub-transmission lines L2 to L5 is determined based on the Equation (9).

On the other hand, at step S4, the optimum structural parameter ξ_{opt} is determined based on the optimization of energy coupling. Then at step S5, the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 is determined based on the Equation (10). Concretely, at steps S2 and S4, such a structural parameter w and a medium parameter ξ are determined so that the real part $\mathrm{Re}[Z_0(w, \xi)]$ of the dimensionless impedance $Z_0 = Z'_0(w, \xi)$ for k = 0 determined by the n-layer recursion formula of the Equation (1) becomes the minimum, and then, the resulting values are taken as the optimized structural parameter w_{opt} and the medium parameter ξ_{opt}.

FIG. 15 is a flow chart showing a flow for determining the minimized surface resistance Rs in the half-wavelength line type resonator according to the present invention. As shown in FIG. 15, at step S11, the value of $\mathrm{Re}[Z_0(w_{opt}, \xi_{opt}]$ is determined based on the n-layer recursion formula of the Equation (1) from the optimized structural parameter w_{opt} and the optimized medium parameter ξ_{opt}. Then at step S12, the minimized surface resistance Rs is determined by substituting the value of $\mathrm{Re}[Z_0(w_{opt}, \xi_{opt})]$ determined at step S11, the electric conductivity σ of each of the thin film conductors 21 to 25, and the skin depth δo into the Equation (8).

In the present embodiment, the effective dielectric constant of each of the thin film dielectrics 31 to 34 constituting the sub-transmission lines L2 to L5 is preferably set to be smaller than the effective dielectric constant of the dielectric substrate 10 constituting the main transmission line L1. By this arrangement, the phase velocity of the electromagnetic wave which propagates through the first transmission line L1 and the phase velocity of the TEM wave which propagates through at least one of the second transmission lines L2 to L5 can be substantially made equal to each other.

In the present embodiment, the thickness of each of the thin film dielectrics 31 to 34 constituting the sub-transmission lines L2 to L5 is made smaller than the thickness of the dielectric substrate 10 constituting the main transmission line L1. By this arrangement, a time required for a film forming process of the sub-transmission lines L2 to L5 can be reduced, and a low-impedance transmission line having an impedance lower than that of the sub-transmission lines L2 to L5 can be constituted, then, this results in a reduced transmission loss.

In the above determination flows of FIG. 14 and FIG. 15, the dielectric constant ε_s of each of the thin film dielectrics 31 to 34 is previously given and then their film thickness Δx_s is determined. However, the present invention is not limited to this, but it may be arranged so that, as apparent from the Equation (4), the film thickness Δx_s of each of the thin film dielectrics 31 to 34 is previously given and then their dielectric constant ε_s may be determined.

In addition, since it is assumed that the electromagnetic fields are uniform in the widthwise direction of the transmission lines L1 to L5, determination of the film thickness in the above-mentioned optimization will be affected neither by the substrate thickness Δx_m of the dielectric substrate 10 of the main transmission line L1 nor by (the line width) = (the width of each of the thin film conductors 21 to 25) = (the width Δy of each of the thin film dielectrics 31 to 34).

The present inventors has made computer simulation based on the equivalent circuit of the half-wavelength line type resonator which is described with reference to FIG. 4, and its results are shown hereinafter. FIG. 5 is a graph

showing a frequency characteristic of a transmission coefficient S_{21}, and FIG. 6 is a graph showing frequency characteristics of relative amplitudes of currents flowing through the thin film conductors 21 to 25 of the half-wavelength line-type resonator of FIG. 1. In FIG. 6, reference numbers I1 to I5 denote the values of the relative amplitudes of the currents flowing through the thin film conductors 21 to 25, respectively. FIG. 7 is a graph showing frequency characteristics of phase differences of currents flowing through the thin film conductors 21 to 25 of the half-wavelength line type resonator of FIG. 1. In FIG. 7, reference numbers P1 to P5 denote the values of phase differences of the currents flowing through the thin film conductors 21 to 25, respectively. In this case, the parameters for the present simulation were set as follows:

(a) the relative dielectric constant (effective value) ε_{mr} of the dielectric substrate 10 = 6.43,
(b) the substrate thickness Δx_m of the dielectric substrate 10 = 330 μm,
(c) the relative dielectric constant ε_{sr} of each of the thin film dielectrics 31 to 34 = 3.80,
(d) the film thickness of each of the thin film dielectrics 31 to 34 Δx_s = 1.40 μm,
(e) the electric conductivity σ of each of the thin film conductors 21 to 25 = 5.80×10^7 S/m (material: Cu),
(f) the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 = 0.97 μm,
(g) the electric conductivity of the earth conductor 11 $\sigma = 5.80 \times 10^7$ S/m (material: Cu), and
(h) the film thickness of the earth conductor 11 $\Delta\xi_m$ = 5.00 μm.

As understood from FIG. 5, a transmission characteristic was obtained which has a transmission coefficient S_{21} = approximately -0.042 dB at a center frequency of 2000 MHz.

Also, as understood from FIG. 6, the relative amplitudes of the currents flowing through the thin film conductors 21 to 25 become the maximum at a resonance frequency of 2000 MHz. The relative amplitudes of the currents flowing through the thin film conductors 21 to 25 at the same resonance frequency attenuates increasingly in the order from the thin film conductor 21 toward the thin film conductor 25. At the same time, the high frequency electromagnetic field energy flowing through the main transmission line L1 transfers to the thin film dielectrics 31 to 34 via the thin film conductors 21 to 25 each having a loss.

Further, as understood from FIG. 7, the phase differences of the currents flowing through the thin film conductors 21 to 25 become 0° at the resonance frequency of 2000 MHz and are equal to each other, and further, the phase differences are approximately ± 90° at frequencies of 1990 and 2010 MHz.

FIG. 8 is a graph showing frequency characteristics of the transmission coefficients S_{21} with the number n of multilayered layers used as a parameter, which are simulation results of the half-wavelength line type resonator of FIG. 3, FIG. 9 is a graph showing a normalized conductor film thickness $\Delta\xi/\delta o$ to Q increasing rate RQ characteristic with the number n of multilayered layers used as a parameter, and FIG. 10 is a graph showing effective dielectric constant ratio $\varepsilon_s/\varepsilon_m$ to normalized dielectric film thickness $\Delta x_s/\delta o$ characteristics with the number n of multilayered layers used as a Parameter. In this case, the parameters for the present simulation were set as follows:

(a) the relative dielectric constant (effective value) ε_{mr} of the dielectric substrate 10 = 90,
(b) the substrate thickness Δx_m of the dielectric substrate 10 = 500 μm,
(c) the relative dielectric constant ε_{sr} of each of the thin film dielectrics 31 to 34 = 40.2,
(d) the film thickness Δx_s of each of the thin film dielectrics 31 to 34 = 1.27 μm,
(e) the electric conductivity σ of each of the thin film conductors 21 to 25 = 6.00×10^7 S/m (material: Ag),
(f) the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 = 1.27 μm,
(g) the electric conductivity σ of the earth conductor 11 = ∞ (infinite),
(h) the film thickness $\Delta\xi_m$ of the earth conductor 11 = a finite value, and
(i) the line length L = 15.8 mm.

It is noted that the earth conductor 11 was assumed to be a perfect conductor in order to evaluate only the thin film multilayered electrode in the present simulation. This is actually equivalent to a structure which results when a mirror image is given with respect to a symmetrical plane of the boundary plane to a perfect conductor. That is, it corresponds to a model in which the thickness of the dielectric substrate 10 is doubled and a thin film multilayered electrode is formed on its both surfaces.

As apparent from FIG. 8, it can be understood that as the number n of multilayered layers is increased, the transmission coefficient S_{21} at the resonance frequency (1000 MHz) increases, with the Q value also increasing. The optimum parameters w_{opt} and ξ_{opt}, the real part Re[Z_0], the Q value, and the Q increasing rate RQ at various numbers n of multilayered layers are shown in Table 1, where the Q value = 485 when n = 1.

Table 1

Number n of multilayered layers	w_{opt}	ξ_{opt}	$Re[Z_0]$	Q value	Q increasing rate RQ
2	2.0424	0.9984	0.6912	720	1.4468
5	1.2376	0.6168	0.4439	1090	2.2526
10	0.8703	0.4348	0.3146	1540	3.1788
25	0.5437	0.2718	0.1991	2330	5.0225
50	0.3920	0.1960	0.1408	3440	7.1025

Also, as apparent from FIG. 9, it can be understood that as the number n of multilayered layers is increased, the maximum RQm of Q increasing rate RQ with Q value for n = 1 taken as a reference value increases, and that the maximum RQm of Q increasing rate can be obtained at a smaller predetermined value of normalized conductor film thickness $\Delta\xi/\delta o$.

Further, FIG. 10 shows results of calculating the relation between the normalized dielectric film thickness $\Delta x_s/\delta o$ and the effective dielectric constant ratio $\varepsilon_s/\varepsilon_m$ based on the equations resulting when the values of the optimum parameter w_{opt} of Table 1 are substituted into the Equation (4). As apparent from FIG. 10, it can be understood that the smaller the effective dielectric constant ratio $\varepsilon_s/\varepsilon_m$ of each of the sub-transmission line L2 to L5 to the main transmission line L1 is, the smaller the film thickness Δx_s of each of the, thin film dielectrics 31 to 34 of the sub-transmission lines L2 to L5 can be made.

An operation of the half-wavelength line type resonator having the above-mentioned arrangement will be described hereinafter.

As previously described,

(a) the film thickness Δx_s and the dielectric constant ε_s of each of the thin film dielectrics 31 to 34 are set to the predetermined values, so that the phase velocities of the TEM waves which propagate through the transmission lines L1 to L5 are made substantially equal to one another; and

(b) the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 is set to the predetermined film thickness smaller than the skin depth δo of the frequency which is used, so that between the adjacent transmission lines L1 and L2, L2 and L3, L3 and L4, and L4 and L5, their electromagnetic fields are coupled with each other. By this arrangement, the high frequency energy flowing through the main transmission line L1 is transferred to the sub-transmission lines L2 to L5, so that the high frequency currents substantially uniformly flow through the thin film conductors 21 to 25, and then, the skin effect due to the high frequency is remarkably suppressed.

FIG. 21 is a schematic longitudinal sectional view of the half-wavelength line type resonator of FIG. 1 in the longitudinal direction, showing its operation, where it is reduced in scale in the longitudinal direction remarkably greater than in the direction of thickness thereof. In FIG. 21, the high frequency current is indicated by solid lines and the displacement current is indicated by dotted lines.

When the resonator is excited by a high frequency signal inputted to the main transmission line L1, as shown in Fig. 25, the thin film conductors 21 to 25 transmit a part of the high frequency power, which is incident onto the thin film conductors via the thin film dielectrics on the lower side thereof, onto the side thin film conductors on the upper side, and while reflecting a part of the energy of the high frequency signal to the thin film conductors on the lower side via the thin film dielectrics on the lower side. Further, within the thin film dielectrics 31 to 34 sandwiched by the adjacent two thin film conductors, the reflection waves and the transmission waves resonate to each other, while two high frequency currents facing to each other in opposite directions (hereinafter, referred to as facing two high frequency currents) flow in the vicinity of the upper surfaces and in the vicinity of the lower surfaces of each of the thin film conductors 21 to 25. That is, since the film thickness of each of the thin film conductors 21 to 25 is smaller than the skin depth δo, the facing two high frequency currents in opposite directions interfere with each other via the thin film dielectrics, and then are cancelled by each other except some remaining portions thereof. On the other hand, the displacement currents are generated by electromagnetic fields in the thin film dielectrics 31 to 34, and this leads to high frequency currents on the surfaces of the adjacent thin film conductors. In the half-wavelength line type resonator, as shown in FIG. 21, the displacement currents become the maximum at the longitudinal both ends of the line and become the minimum at the center of the line.

In this case, if the case is ideal, the amplitudes of the high frequency currents of the thin film conductors 21 to 25 becomes constant, and then, the conductor loss becomes the theoretical possible minimum, as shown in FIG. 12. How-

ever, in an actual case, the amplitudes of the high frequency currents of the thin film conductors 21 to 25 have distributions different from each other as shown in FIG. 13, and when the upper the thin film conductor is, the more the amplitudes of the high frequency currents decreases. It is noted that in all of FIGs. 11, 12, and 13, the total current values proportional to the area of hatched portions are made coincident with one another for comparison.

Further, since the film thickness Δx_s and the dielectric constant ε_s for determining the effective dielectric constant of each of the thin film dielectrics 31 to 34 are so set that the phase velocities of the TEM waves propagating through the transmission lines L1 to L5 are made substantially equal to one another, the high frequency currents flowing through the thin film conductors 21 to 25 are substantially in phase to one another. Then, the high frequency currents flowing through the thin film conductors 21 to 25 in phase cause the skin depth δo to increase effectively.

Accordingly, if the resonator is excited by a high frequency signal, the high frequency electromagnetic field energy transfers to the upper transmission lines by the coupling between the electromagnetic fields of the adjacent transmission lines, while propagating in the longitudinal direction of the transmission lines of the resonator. In this case, the resonator is brought into a resonance state, since the TEM waves propagate with an effectively greater skin depth δo, i.e. a smaller surface resistance R_s, and reflect at the both ends of the half-wavelength line.

FIG. 28 is a graph showing relative amplitudes of currents flowing through the thin film conductors 21 to 25 and the earth conductor 11 relative to the distance of transmission of the half-wavelength line type resonator of FIG. 1. In this case, the parameters for the present simulation were set as follows:

(a) the relative dielectric constant (effective value) ε_{mr} of the dielectric substrate 10 = 8.85,
(b) the substrate thickness Δx_m of the dielectric substrate 10 = 330 μm,
(c) the relative dielectric constant ε_{sr} of each of the thin film dielectrics 31 to 34 = 3.80,
(d) the electric conductivity σ of each of the thin film conductors 21 to 25 = 5.18×10^7 S/m (material: Cu),
(e) the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 = 0.97 μm,
(f) the electric conductivity σ of the earth conductor 11 = 5.18×10^7 S/m (material: Cu),
(g) the film thickness $\Delta\xi_m$ of the earth conductor 11 = 10.00 μm,
(h) (the width of each of the thin film conductors 21 to 25) = (width of each of the thin film dielectrics 31 to 34) = (the width of the dielectric substrate 10) = (the width of the earth conductor 11) = 5.00 mm,
(i) the film thickness Δx_s of each of the thin film dielectrics 31 to 34 = 0.73 μm, and
(j) the line length L = 25.1333 mm.

In FIG. 28, Ig and I1 to I5 denote the relative amplitudes of the currents flowing through the earth conductor 11 and the thin film conductors 21 to 25, respectively. As apparent from FIG. 28, the currents flowing through the earth conductor 11 and the thin film conductors 21 to 25 are divided and shunt with predetermined rates, constituting respective standing waves.

Therefore, the resonator of the present embodiment has the following characteristic advantages:

(a) since the thin film multilayered electrode is provided, the skin depth can be effectively increased, so that the conductor loss and the surface resistance can be reduced substantially as compared with the conventional counterpart. This makes it possible to offer a resonator or filter with an extremely large no-loaded Q in smaller size and weight; and
(b) in the case of a microstrip line, for example, a line impedance can be changed without changing the line width, by using a thin film multilayered transmission line or not using it, or by changing the number of the multilayered layers. This facilitates pattern design on the dielectric substrate.

According to the simulation by the present inventor, it can be seen that a decreasing rate of the surface resistance Rs is in inverse proportion to the number n of multilayered layers in the ideal case of FIG. 12. On the other hand, in the actual case of FIG. 13, it can be seen that the decreasing rate of the surface resistance Rs is in inverse proportion to the square root of the number n of the multilayered layers.

It may be constituted so that only the earth conductor 11 of the first embodiment have the structure of the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode, and the remaining conductors have the known conventional structures. Alternatively, the earth conductor 11 may be provided so as to be have the structure of the above-mentioned high frequency electromagnetic field coupled type thin film multilayered electrode in a manner as shown in FIG. 27. As shown in FIG. 27, a thin film conductor 21a, a thin film dielectric 31a, a thin film conductor 22a, a thin film dielectric 32a, a thin film conductor 23a, a thin film dielectric 33a, a thin film conductor 24a, a thin film dielectric 34a, and a thin film conductor 25a are multilayered in this order on the rear surface of the dielectric substrate 10. In this case, an operation of the resonator shown in FIG. 27 is similar to that of the resonator shown in FIG. 1. Further, a protection dielectric may be formed on the thin film conductor 25 of the top layer of the first embodiment, and on a thin film conductor 25a of an embodiment modified from the first embodiment. Further, the entire body of the resonator may be enclosed or covered by a protection dielectric.

In the first embodiment described hereinabove, the main transmission line L1 and the sub-transmission lines L2 to L5 are the microstrip lines. However, the present invention is not limited to this, and they may also be transmission lines such as tri-plate type strip lines, coplanar lines, slot lines or the like. In this case, thin film multilayered conductors according to the present invention may be used for at least either one of the center conductor and the earth conductor.

In the above-mentioned first embodiment, the film thickness Δx_s and the dielectric constant ε_s of each of the thin film dielectrics 31 to 34 are set so that the phase velocities of the TEM waves propagating through the transmission lines L1 to L5 are made substantially equal to one another. However, the present invention is not limited to this, but it may alternatively be arranged so that the phase velocities of the TEM waves propagating through the main transmission line L1 and at least one of the sub-transmission lines L2 to L5 are made substantially equal to each other. Further, it may also be arranged so that only at least one of the sub-transmission lines L2 to L5 is provided.

Also, in the above first embodiment, the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 is so set that the electromagnetic fields are coupled with each other between the adjacent transmission lines L1 and L2, L2 and L3, L3 and L4, and L4 and L5. However, the present invention is not limited to this, and it may alternatively be arranged so that the electromagnetic fields are coupled with each other between the main transmission line L1 and at least one of the sub-transmission lines L2 to L5.

Further, in the above-mentioned first embodiment, the main transmission line L1 is the TEM mode transmission line. However, the present invention is not limited to this, and the main transmission line L1 may also be a transmission line for propagating therethrough electromagnetic waves of the other kind of mode such as a TE mode, a TM mode, or the like.

In the above-mentioned first embodiment, the filter using the half-wavelength line type resonator using the electromagnetic field coupled type thin film multilayered transmission line is described. However, the present invention is not limited to this, and a filter using a quarter-wavelength line type resonator using an electromagnetic field coupled type thin film multilayered transmission line may be constituted. Furthermore, by coupling an input transmission line with the electromagnetic field coupled type thin film multilayered transmission line, and coupling an output transmission line with the electromagnetic field coupled type thin film multilayered transmission line, respectively, via relatively strong electromagnetic couplings, the electromagnetic field coupled type thin film multilayered transmission line can be used as a transmission line having an extremely low loss. Simulation results of the electromagnetic field coupled type thin film multilayered transmission line will be described hereinafter.

FIG. 25 is a graph showing effective current values of currents flowing through the thin film conductors 21 to 25 and the earth conductor 11 relative to a distance of transmission from the input terminal in the case where the film thickness Δx_s of each of the thin film dielectrics 31 to 34 is decreased from 0.73 μm to 0.36 μm in the thin film multilayered transmission line according to the present invention, and FIG. 26 is a graph showing effective current values of currents flowing through the thin film conductors 21 to 25 and the earth conductor 11 relative to a distance of transmission from the input terminal in the case where the film thickness Δx_s of each of the thin film dielectrics 31 to 34 is increased from 0.73 μm to 1.37 μm in a thin film multilayered transmission line according to the present invention. In the above cases, the parameters for the present simulation were set as follows:

(a) the relative dielectric constant ε_{mr} of the dielectric substrate 10 (effective value) = 8.85,
(b) the substrate thickness Δx_m of the dielectric substrate 10 = 330 μm,
(c) the electric conductivity σ of each of the thin film conductors 21 to 25 = 5.18×10^7 S/m (material: Cu),
(d) the film thickness $\Delta\xi$ of each of the thin film conductors 21 to 25 = 0.97 μm,
(e) the electric conductivity σ of the earth conductor 11 = 5.18×10^7 S/m (material: Cu),
(f) the film thickness $\Delta\xi_m$ of the earth conductor 11 = 10.00 μm,
(g) (the width of the thin film conductors 21 to 25) = (the width of the thin film dielectrics 31 to 34) = (the width of the dielectric substrate 10) = (the width of the earth conductor 11) = 5.00 mm, and
(h) the input transmission power = 0.1 mW = -10 dBm.

In FIGs. 25 and 26, Ig, I_1, I_2, I_3, I_4 and I_5 are effective current values of currents flowing through respectively the earth conductor 11 and the thin film conductors 21 to 25 when the dielectric constant ε_{sr} of each of the thin film dielectrics 31 to 34 is 3.8 and their film thickness Δx_s is 0.73 μm. In FIG. 25, Iga, I_1a, I_2a, I_3a, I_4a and I_5a are effective current values of currents flowing through respectively the earth conductor 11 and the thin film conductors 21 to 25 when the dielectric constant ε_{sr} of each of the thin film dielectrics 31 to 34 is 2.4 and their film thickness Δx_s is 0.36 μm. Further, in FIG. 26, Igb, I_1b, I_2b, I_3b, I_4b and I_5b are effective current values of currents flowing through respectively the earth conductor 11 and the thin film conductors 21 to 25 when the dielectric constant ε_{sr} of each of the thin film dielectrics 31 to 34 is 5.2 and their film thickness Δx_s is 1.37 μm.

As apparent from FIGs. 25 and 26, only the main transmission line L1 is excited at the input terminal, and a current also permeates or flows to the sub-transmission lines L2 to L5 as the microwave signal propagates. Then the current value of the current flowing through each of the transmission lines L1 to L5 becomes constant when the signal propagates from the input terminal by about four wavelengths. It can be understood that a power of about 99.5% of the total trans-

mission power is transmitted to the main transmission line L1 in the present model, while the other remaining transmission power is distributed into the sub-transmission lines L2 to L5. Further, by comparing FIG. 25 with FIG. 26, it can be understood that a distance of convergence of the permeating current is reduced by thinning the film thickness Δx_s of each of the thin film dielectrics 31 to 34. That is, by thinning the film thickness Δx_s of each of the thin film dielectrics 31 to 34, the current immediately or suddenly permeates in the vicinity of the input terminal. When FIG. 4 is regarded as a transmission line, a reduced conversion loss results in the connection or coupling between the input or output terminal and the multi-layer transmission line.

Second Embodiment

FIG. 16 is a circuit diagram showing an equivalent circuit of a half-wavelength line type resonator filter using an electromagnetic field coupled type thin film multilayered transmission line which is a second embodiment according to the present invention.

Although only the main transmission line L1 is excited in the above-mentioned first embodiment, it may also be arranged so that all the transmission lines L1 to L5 are excited in a manner similar to that of the second embodiment. Hereinbelow, only differences from the first embodiment will be described.

As shown in FIG. 16, respective primary turns of ideal transformers T11, T21, ..., T51 respectively connected to the transmission lines L1 to L5 are connected in series, and a series circuit of a signal generator Vsg and its internal resistance Rsg is connected across both the ends of the primary turns connected in series. On the other hand, respective secondary turns of ideal transformers T12, T22, ..., T52 on the opposite end side are connected in series, and a load resistance R_L is connected across both the ends of the secondary turns connected in series.

FIG. 17 is a graph showing frequency characteristic of a transmission coefficient S_{21}, which is a simulation result of the half-wavelength line type resonator of FIG. 16. In this case, the parameters for the present simulation were set in the same way as that in FIG. 5.

As understood from FIG. 17, a resonance characteristic having a transmission coefficient S_{21} = approximately -0.050 dB was obtained at a center frequency of 2000 MHz.

In the above-mentioned second embodiment, it may alternatively be arranged so that the transmission lines L1 to L5 are excited to be weighted by using a variable amplifier or a variable attenuator, and an in-phase divider. In this case, distribution of electromagnetic field energies propagating in the transmission lines L1 to L5 can be changed.

Third Embodiment

FIG. 18 is a perspective view of a quarter-wavelength line type band-elimination filter using an electromagnetic field coupled type thin film multilayered transmission line which is a third embodiment according to the present invention.

In the third embodiment, as shown in FIG. 18, a microstrip line L10 is formed by forming a microstrip conductor 41 on a dielectric substrate 10 having an earth conductor 11 formed on its entire rear surface. Then, the thin film multilayered electrode of the first embodiment comprising the thin film conductors 21 to 25 and the thin film dielectrics 31 to 34 and having a length of 1/4 λg is formed so that the lowest thin film conductor 21 is positioned a gap g3 away from and close to the microstrip conductor 41 of the microstrip line L10 enough to be electromagnetically coupled therewith, and that the longitudinal directions of the thin film conductors 21 to 25 and the thin film dielectrics 31 to 34 are parallel to the longitudinal direction of the microstrip conductor 41.

FIG. 19 is a circuit diagram including an equivalent circuit of the quarter-wavelength line type band-elimination filter of FIG. 18.

As shown in FIG. 19, the microstrip line L10 is made up of a distributed constant circuit in which LC unit distributed constant circuits are connected in series and which comprises inductors L100, L101, ..., L10n, L10(n+1) and capacitors C100, C101, ..., C10n, C10(n+1). A resonator-exciting signal generator Vsg and its internal resistance Rsg are connected to one end of the microstrip line L10, while a load resistance R_L is connected to another end of the microstrip line L10. In the main microstrip line L10, ideal transformers T610, T611, ..., T61n, T61(n+1) are inserted so as to be connected to the lower line in the figure between the unit distributed constant circuits. The ideal transformers T610, T611, ..., T61n, T61(n+1) are grounded via four-terminal circuits F60, F61, ..., F6n, F6(n+1) each of which comprises a distributed constant circuit corresponding to the earth conductor 11 and including a loss resistance and via ideal transformers T600, T601, ..., T60n, T60(n+1).

Also, in the microstrip line L10, ideal transformers T620, T621, ..., T62n, T62(n+1) are inserted so as to be connected to the upper line in the figure between the unit distributed constant circuits. The ideal transformers T620, T621, ..., T62n, T62(n+1) are connected to load resistances R_{L10}, R_{L11}, ..., R_{L1n}, $R_{L1(n+1)}$, respectively, via the microstrip conductor 41 and four-terminal circuits F70, F71, ..., F7n, F7(n+1) corresponding to the space positioned above the microstrip conductor 41.

Further, inductive coupling and capacitive coupling is generated by the gap g3 as follows. That is, the inductors L11 and L101 are inductively coupled (M) with each other, the inductors L12 and L102 are inductively coupled (M) with each

other, and the following goes likewise, so that the inductors L1n and L10n are inductively coupled (M) with each other. Also, the capacitors C11 and C101 are capacitively coupled (C) with each other, the capacitors C12 and C102 are capacitively coupled (C) with each other, and the following goes likewise, so that the capacitors C1n and C10n are capacitively coupled (C) with each other.

In the circuit arranged as described above, a resonator with an extremely small conductor loss can be provided by the quarter-wavelength line type thin film multilayered transmission line. Accordingly, by forming a microstrip line L10 which is electromagnetically coupled with the resonator, a quarter-wavelength line type band-elimination filter having an extremely large no-loaded Q can be provided.

Although the microstrip line L10 is used in the above-mentioned third embodiment, the present invention is not limited to this. It may be replaced with the other kind of transmission line such as a coplanar line, a slot line, a tri-plate type strip line, or the like.

Modified Embodiment

Further, in modified embodiments as described below, use of an electromagnetic field coupled type thin film multilayered electrode according to the present invention makes it possible to reduce the surface resistance of the electrode remarkably as compared with the conventional counterpart, and this results in that the transmission loss can be remarkably reduced.

FIG. 20 (a) is a perspective view of a microstrip line using the electromagnetic field coupled type thin film multilayered electrode according to the present invention, and the electromagnetic field coupled type thin film multilayered electrode is used for a microstrip conductor 51 and an earth conductor 52 of the microstrip line. It is noted that the electromagnetic field coupled type thin film multilayered electrode may be used only for the microstrip conductor 51, and the electromagnetic field coupled type thin film multilayered electrode may be used only for the earth conductor 52.

Also, FIG. 20 (b) is a perspective view of a tri-plate type strip line using the electromagnetic field coupled type thin film multilayered electrode according to the present invention, and the electromagnetic field coupled type thin film multilayered electrode is used for a microstrip conductor 61 and earth conductors 62 and 63 of the above-mentioned strip line. It is noted that the electromagnetic field coupled type thin film multilayered electrode may be used only for the microstrip conductor 61, and the electromagnetic field coupled type thin film multilayered electrode may be used only for at least one of the earth conductors 62 and 63.

Further, FIG. 20 (c) is a perspective view of a coaxial line using the electromagnetic field coupled type thin film multilayered electrode according to the present invention, and the electromagnetic field coupled type thin film multilayered electrode is used for a center conductor 71 and an earth conductor 72 of the above-mentioned coaxial line. It is noted that the electromagnetic field coupled type thin film multilayered electrode may be used only for the center conductor 71, and the electromagnetic field coupled type thin film multilayered electrode may be used only for the earth conductor 72.

Still further, FIG. 20 (d) is a longitudinal sectional view of a TM_{01} mode circular waveguide using the electromagnetic field coupled type thin film multilayered electrode 73 according to the present invention, and the electromagnetic field coupled type thin film multilayered electrode is used for an outer-surface electrode of the circular waveguide. Further, the electromagnetic field coupled type thin film multilayered electrode may be used for an outer-surface electrode of a rectangular waveguide (not shown).

Further, the electromagnetic field coupled type thin film multilayered electrode according to the present invention can be applied to electrode-film portions formed on the outer surface of a cavity in a TM mode single mode type dielectric resonator in which a core dielectric and the cavity are integrally formed so as to be molded, such as disclosed in, for example, the Japanese Patent Laid-Open Publication No. HEISEI 03 (1991)-292006 (the Japanese Patent Application No. HEISEI 02 (1990)-094862). Also, the TM mode dielectric resonator is not limited to the TM mode single mode type, and the electromagnetic field coupled type thin film multilayered electrode can also be applied to a double mode type dielectric resonator (for example, see FIG. 23) such as disclosed in, for example, the Japanese Patent Laid-Open Publication No. SHOWA 63 (1988)-313901 (the Japanese Patent Application No. SHOWA 62 (1987)-150021), and can be further applied to a triple mode type dielectric resonator such as disclosed in, for example, the Japanese Patent Laid-Open Publication No. SHOWA 61 (1986)-157101 (the Japanese Patent Application No. SHOWA 59 (1984)-279203). That is, irrespectively of the number of modes used, the electromagnetic field coupled type thin film multilayered electrode according to the present invention can be applied to an electrode-film portion of TM mode dielectric resonators.

FIG. 23 shows an example of a double mode type dielectric resonator 75 which is a modified embodiment of the present invention. The double mode type dielectric resonator 75 is built up in such a way that at a center portion within a square-cylindrical resonator casing 77 in which the outer surface of the dielectric has been metallized, a cross-shaped dielectric 76 formed integrally so as to be molded with the casing 77 is provided. In this case, the electrode of the resonator casing 77 is provided by using the electromagnetic field coupled type thin film multilayered electrode according to the present invention. This results in that the surface resistance of the electrode can be remarkably reduced, and then, the loss of the dielectric resonator can be reduced while its no-loaded Q can be increased.

FIG. 24 shows an example of a $TM_{01\delta}$ mode type two-stage dielectric band-pass filter 80 which is a modified embodiment of the present invention. The band-pass filter 80 is made up in the following way. That is, SMA connectors 83 and 84 for input and output are attached at both ends of a cylindrical dielectric waveguide 81 having an outer-peripheral electrode 82. The earth conductors of the SMA connectors 83 and 84 are connected to the outer-peripheral electrode 82, while monopole antennas 85 and 86 opposed to each other within the dielectric waveguide 81 are connected to center conductors of the SMA connectors 83 and 84, respectively. Within the dielectric waveguide 81 between the monopole antennas 85 and 86, two circular-cylindrical dielectric resonators 87 and 88 are provided a predetermined interval away from each other and via ring-shaped dielectric supports 89 and 90 in internal connection with the inner peripheral surface of the dielectric waveguide 81. Also in the band-pass filter 80, the outer-peripheral electrode 82 is provided by the use of the electromagnetic field coupled type thin film multilayered electrode according to the present invention. This allows the surface resistance of the outer-peripheral electrode 82 to be remarkably reduced so that the loss of the dielectric filter can be reduced while its no-loaded Q can be increased.

Further, the electromagnetic field coupled type thin film multilayered electrode according to the present invention can be applied to electrodes of various types of high frequency devices intended for their respective specific high frequency operations such as those of isolators, antennas, inductors such as chip coils, capacitors or the like.

In the above-mentioned embodiments, the solid thin film dielectrics 31 to 34 are used, however, the present invention is not limited to this, and gas such as air or liquid may be substituted for the thin film dielectrics 31 to 34.

In the above-mentioned embodiments, the thin film dielectrics 31 to 34 have the same film thickness, however, the present invention is not limited to this, and the respective film thicknesses of the thin film dielectrics 31 to 34 may be set to be different from each other.

In the above-mentioned embodiments, the thin film conductors 21 to 24 have the same film thickness, however, the present invention is not limited to this, and the respective film thicknesses of the thin film conductors 21 to 24 may be set to be different from each other.

In the above-mentioned embodiments, the earth conductor 11 and the thin film conductors 21 to 25 are made of a conductor having an electric conductivity such as Cu, Ag, Au or the like, however, the present invention is not limited to this, and as at least one material of the earth conductor 11 and the thin film conductors 21 to 25, there may be used any of the following superconductors:

(a) a pure metal superconducting material such as Nb, Pb, or the like;
(b) a superconducting material of an alloy such as an Nb-Ti alloy, an Nb-Zr alloy, or the like;
(c) an intermetallic compound superconducting material such as Nb_3Sn, V_3Si or the like; and
(d) a ceramic group oxide superconducting material exemplified by:
(d-1) $La_{2-x}Ba_xCuO_{4-\delta}$ or $La_{2-x}Sr_xCuO_{4-\delta}$ such as $La_{1.85}Sr_{0.15}CuO_4$ or the like;
(d-2) $YBa_2Cu_3O_{7-\delta}$ (amount of oxygen deficiency $\delta = 0$ to 1) such as $YBa_2Cu_3O_7$ or the like;
(d-3) a Bi-Sr-Ca-Cu-O group, the Bi-Sr-Ca-Cu-O group superconducting material being obtained by temporarily baking a powder of a mixture of Bi_2O_3, $SrCo_3$, $CaCO_3$ and CuO at a temperature of 800 to 870°C and thereafter sintering the powder in an atmosphere at a temperature of 850 to 880°C;
(d-4) a Tl-Ba-Ca-Cu-O group, the Tl-Ba-Ca-Cu-O group superconducting material being obtained as a superconducting material having a main component of $Tl_2CaBa_2Cu_2O_x$ by mixing and shaping powders of Tl_2O_3, CaO, BaO and CuO and thereafter sealingly inserting the shaped mixture of the powders in a silica tube including an oxygen gas at one atmospheric pressure and heating the same at a temperature of 880 °C for three hours;
(d-5) an EBCO group; and
(d-6) a BPSCCO group;
(e) an organic substance superconducting material exemplified by:
(e-1) a tetramethyltetraselenafulvalene (TMTSF) superconducting material such as $(TMTSF)_2ClO_4$ or the like;
(e-2) a bis(ethylenedithiolo)tetrathiafulvalene (BEDT-TTF) superconducting material such as $\beta(BEDT\text{-}TTF)_2I_3$ or the like; and
(e-3) a dmit group superconducting material.

INDUSTRIAL APPLICABILITY

As described above, according to the present invention, there is provided a thin film multilayered electrode in which thin film conductors (21-25) and thin film dielectrics (31-34) are alternately multilayered so that a plurality of TEM mode transmission lines (L2-L5) are stacked or multilayered, the TEM mode transmission lines (L2-L5) each comprising a pair of the thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of the thin film dielectrics (31-34) is sandwiched, wherein phase velocities of TEM waves which propagate through at least two of the plurality of TEM mode transmission lines (L2-L5) are made substantially equal to each other, and the film thickness of each of the thin film conductors (21-25) is made smaller than the skin depth of a frequency used so that electromagnetic fields of at least two of the plurality of TEM mode transmission lines (L2-L5) are coupled with each other. Accordingly, the skin

depth is effectively increased, and then, the conductor loss and the surface resistance can be reduced remarkably as compared with those of the conventional counterpart, while remarkably preventing the external dimensions from increasing as compared with the conventional structure. Use of the thin film multilayered electrode of the present invention makes it possible to offer high frequency transmission lines with smaller transmission loss, high frequency resonators or high frequency filters each having an extremely large no-loaded Q, or high frequency devices each having smaller size and weight.

Claims

1. A high frequency electromagnetic field coupled type thin film multilayered electrode characterized in that
   thin film conductors (21-25) and thin film dielectrics (31-34) are alternately stacked so that a plurality of TEM mode transmission lines (L2-L5) are multilayered, said TEM mode transmission lines (L2-L5) each comprising a pair of said thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of said thin film dielectrics (31-34) are sandwiched,
   wherein phase velocities of TEM waves which propagate through at least two of said plurality of TEM mode transmission lines (L2-L5) are made substantially equal to each other, and a film thickness of each of said thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used, so that electromagnetic fields of at least two of said plurality of TEM mode transmission lines (L2-L5) are coupled with each other.

2. The high frequency electromagnetic field coupled type thin film multilayered electrode as claimed in Claim 1,
   wherein each of said thin film conductors (21-25) is made of a superconducting material.

3. A high frequency transmission line having at least one conductor,
   said conductor comprising a thin film multilayered electrode in which thin film conductors (21-25) and thin film dielectrics (31-34) are alternately stacked so that a plurality of TEM mode transmission lines (L2-L5) are multilayered, each of said TEM mode transmission lines (L2-L5) comprising a pair of said thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of said thin film dielectrics (31-34) is sandwiched,
   wherein phase velocities of TEM waves which propagate through at least two of said plurality of TEM mode transmission lines (L2-L5) are made substantially equal to each other, and a film thickness of each of said thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used, so that electromagnetic fields of at least two of said plurality of TEM mode transmission lines (L2-L5) are coupled with each other.

4. The high frequency transmission line as claimed in Claim 3,
   wherein said high frequency transmission line is a waveguide.

5. A high frequency transmission line comprising:
   a first transmission line (L1); and
   at least one TEM mode second transmission line (L2-L5) in which a thin film conductor (21-25) and a thin film dielectric (31-34) are alternately stacked so that said TEM mode second transmission line (L2-L5) comprises a pair of said thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which said thin film dielectric (31-34) is sandwiched,
   wherein a phase velocity of an electromagnetic wave which propagates through said first transmission line (L1) and a phase velocity of a TEM wave which propagates through at least one of said second transmission lines (L2-L5) are made substantially equal to each other, and a film thickness of each of said thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used, so that an electromagnetic field of said first transmission line (L1) and an electromagnetic field of at least one of said second transmission lines (L2-L5) are coupled with each other.

6. The high frequency transmission line as claimed in Claim 5,
   wherein an effective dielectric constant of each of said thin film dielectrics (31-34) constituting said second transmission lines (L2-L5) is made smaller than an effective dielectric constant of said dielectric constituting said first transmission line (L1).

7. The high frequency transmission line as claimed in Claim 5 or 6,
   wherein a thickness of said thin film dielectric (31-34) constituting said second transmission line (L2-L5) is made smaller than a thickness of said dielectric constituting said first transmission line (L1).

8. The high frequency transmission line as claimed in any of Claims 5 to 7,
   wherein said high frequency transmission line (L1) is a microstrip line.

9. The high frequency transmission line as claimed in Claim 8,
wherein said microstrip line comprises said second transmission line (L2-L5) formed as a microstrip conductor on a first surface of a dielectric substrate (10), and an earth conductor (11) formed on a second surface of said dielectric substrate (10).

10. The high frequency transmission line as claimed in Claim 8,
wherein said microstrip line comprises one of said second transmission line (L2-L5) formed as a microstrip conductor on a first surface of a dielectric substrate (10), and another one of said second transmission line (L2-L5) formed as an earth conductor on a second surface of said dielectric substrate (10).

11. The high frequency transmission line as claimed in any of Claims 5 to 7,
wherein said high frequency transmission line is a strip line.

12. The high frequency transmission line as claimed in any of Claims 5 to 7,
wherein said high frequency transmission line is a coaxial line.

13. The high frequency transmission line as claimed in any of Claims 3 to 12,
wherein at least one of said thin film conductors (21-25) is made of a superconducting material.

14. A high frequency resonator comprising said high frequency transmission line as claimed in any one of Claims 3 to 13 having predetermined dimensions.

15. The high frequency resonator as claimed in Claim 14,
wherein said high frequency transmission line has a length equal to a quarter of a guide wavelength of a signal transmitted through said high frequency transmission line, in a direction in which said signal is transmitted.

16. The high frequency resonator as claimed in Claim 14,
wherein said high frequency transmission line has a length equal to a half of a guide wavelength of a signal transmitted through said high frequency transmission line, in a direction in which said signal is transmitted.

17. The high frequency filter comprising:
a high frequency resonator as claimed in any one of Claims 14 to 16, said high frequency resonator having a predetermined length;
an input terminal (12) for inputting a high frequency signal to said high frequency resonator; and
an output terminal (13) for outputting a high frequency signal from said high frequency resonator.

18. A high frequency band-elimination filter comprising:
a transmission line (L10) for inputting a high frequency signal at one end thereof and outputting said high frequency signal at another end thereof; and
a high frequency resonator as claimed in any of Claims 14 to 16 to be coupled with said transmission line (L10).

19. A dielectric resonator comprising:
a resonator casing (77) including a conductor; and
a dielectric (76) having a predetermined shape, said dielectric being placed within said resonator casing (77),
wherein said conductor is formed of said high frequency electromagnetic field coupled type thin film multilayered electrode as claimed in Claim 1 or 2.

20. A high frequency filter comprising:
a dielectric resonator as claimed in Claim 19;
an input terminal for inputting a high frequency signal to said dielectric resonator, said input terminal electromagnetically coupled with said dielectric resonator; and
an output terminal for outputting a high frequency signal from said dielectric resonator, said output terminal electromagnetically coupled with said dielectric resonator.

21. A high frequency device having an electrode to perform a predetermined high frequency operation;
wherein said electrode comprises a high frequency electromagnetic field coupled type thin film multilayered electrode as claimed in Claim 1 or 2.

Amended claims

1. (Amended) A high frequency electromagnetic field coupled type thin film multilayered electrode characterized in that thin film conductors (21-25) and thin film dielectrics (31-34) are alternately stacked so that a plurality of TEM mode transmission lines (L2-L5) are multilayered, said TEM mode transmission lines (L2-L5) each comprising a pair of said thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of said thin film dielectrics (31-34) are sandwiched,
   wherein a film thickness of each of said thin film dielectrics (31-34) is set so that phase velocities of TEM waves which propagate through at least two of said plurality of TEM mode transmission lines (L2-L5) are made substantially equal to each other, and
   wherein a film thickness of each of said thin film conductors (21-25) is set so as to be smaller than a skin depth of a frequency which is used so that electromagnetic fields of at least two of said plurality of TEM mode transmission lines (L2-L5) are coupled with each other.

2. The high frequency electromagnetic field coupled type thin film multilayered electrode as claimed in Claim 1, wherein each of said thin film conductors (21-25) is made of a superconducting material.

3. (Amended) A high frequency transmission line having at least one conductor,
   said conductor comprising a thin film multilayered electrode in which thin film conductors (21-25) and thin film dielectrics (31-34) are alternately stacked so that a plurality of TEM mode transmission lines (L2-L5) are multilayered, each of said TEM mode transmission lines (L2-L5) comprising a pair of said thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which each of said thin film dielectrics (31-34) is sandwiched,
   wherein a film thickness of each of said thin film dielectrics (31-34) is set so that phase velocities of TEM waves which propagate through at least two of said plurality of TEM mode transmission lines (L2-L5) are made substantially equal to each other, and
   wherein a film thickness of each of said thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used so that electromagnetic fields of at least two of said plurality of TEM mode transmission lines (L2-L5) are coupled with each other.

4. The high frequency transmission line as claimed in Claim 3, wherein said high frequency transmission line is a waveguide.

5. (Amended) A high frequency transmission line comprising:
   a first transmission line (L1); and
   at least one TEM mode second transmission line (L2-L5) in which a thin film conductor (21-25) and a thin film dielectric (31-34) are alternately stacked so that said TEM mode second transmission line (L2-L5) comprises a pair of said thin film conductors (21 and 22, 22 and 23, 23 and 24, and 24 and 25) between which said thin film dielectric (31-34) is sandwiched,
   wherein a film thickness of each of said thin film dielectrics (31-34) is set so that a phase velocity of an electromagnetic wave which propagates through said first transmission line (L1) and a phase velocity of a TEM wave which propagates through at least one of said second transmission lines (L2-L5) are made substantially equal to each other, and
   wherein a film thickness of each of said thin film conductors (21-25) is made smaller than a skin depth of a frequency which is used so that an electromagnetic field of said first transmission line (L1) and an electromagnetic field of at least one of said second transmission lines (L2-L5) are coupled with each other.

6. The high frequency transmission line as claimed in Claim 5, wherein an effective dielectric constant of each of said thin film dielectrics (31-34) constituting said second transmission lines (L2-L5) is made smaller than an effective dielectric constant of said dielectric constituting said first transmission line (L1).

7. The high frequency transmission line as claimed in Claim 5 or 6, wherein a thickness of said thin film dielectric (31-34) constituting said second transmission line (L2-L5) is made smaller than a thickness of said dielectric constituting said first transmission line (L1).

8. The high frequency transmission line as claimed in any of Claims 5 to 7, wherein said high frequency transmission line (L1) is a microstrip line.

9. The high frequency transmission line as claimed in Claim 8,
wherein said microstrip line comprises said second transmission line (L2-L5) formed as a microstrip conductor on a first surface of a dielectric substrate (10), and an earth conductor (11) formed on a second surface of said dielectric substrate (10).

10. The high frequency transmission line as claimed in Claim 8,
wherein said microstrip line comprises one of said second transmission line (L2-L5) formed as a microstrip conductor on a first surface of a dielectric substrate (10), and another one of said second transmission line (L2-L5) formed as an earth conductor on a second surface of said dielectric substrate (10).

11. The high frequency transmission line as claimed in any of Claims 5 to 7,
wherein said high frequency transmission line is a strip line.

12. The high frequency transmission line as claimed in any of Claims 5 to 7,
wherein said high frequency transmission line is a coaxial line.

13. The high frequency transmission line as claimed in any of Claims 3 to 12,
wherein at least one of said thin film conductors (21-25) is made of a superconducting material.

14. A high frequency resonator comprising said high frequency transmission line as claimed in any one of Claims 3 to 13 having predetermined dimensions.

15. The high frequency resonator as claimed in Claim 14,
wherein said high frequency transmission line has a length equal to a quarter of a guide wavelength of a signal transmitted through said high frequency transmission line, in a direction in which said signal is transmitted.

16. The high frequency resonator as claimed in Claim 14,
wherein said high frequency transmission line has a length equal to a half of a guide wavelength of a signal transmitted through said high frequency transmission line, in a direction in which said signal is transmitted.

17. The high frequency filter comprising:
a high frequency resonator as claimed in any one of Claims 14 to 16, said high frequency resonator having a predetermined length;
an input terminal (12) for inputting a high frequency signal to said high frequency resonator; and
an output terminal (13) for outputting a high frequency signal from said high frequency resonator.

18. A high frequency band-elimination filter comprising:
a transmission line (L10) for inputting a high frequency signal at one end thereof and outputting said high frequency signal at another end thereof; and
a high frequency resonator as claimed in any of Claims 14 to 16 to be coupled with said transmission line (L10).

19. A dielectric resonator comprising:
a resonator casing (77) including a conductor; and
a dielectric (76) having a predetermined shape, said dielectric being placed within said resonator casing (77),
wherein said conductor is formed of said high frequency electromagnetic field coupled type thin film multilayered electrode as claimed in Claim 1 or 2.

20. A high frequency filter comprising:
a dielectric resonator as claimed in Claim 19;
an input terminal for inputting a high frequency signal to said dielectric resonator, said input terminal electromagnetically coupled with said dielectric resonator; and
an output terminal for outputting a high frequency signal from said dielectric resonator, said output terminal electromagnetically coupled with said dielectric resonator.

21. A high frequency device having an electrode to perform a predetermined high frequency operation;
wherein said electrode comprises a high frequency electromagnetic field coupled type thin film multilayered electrode as claimed in Claim 1 or 2.

Fig. 1

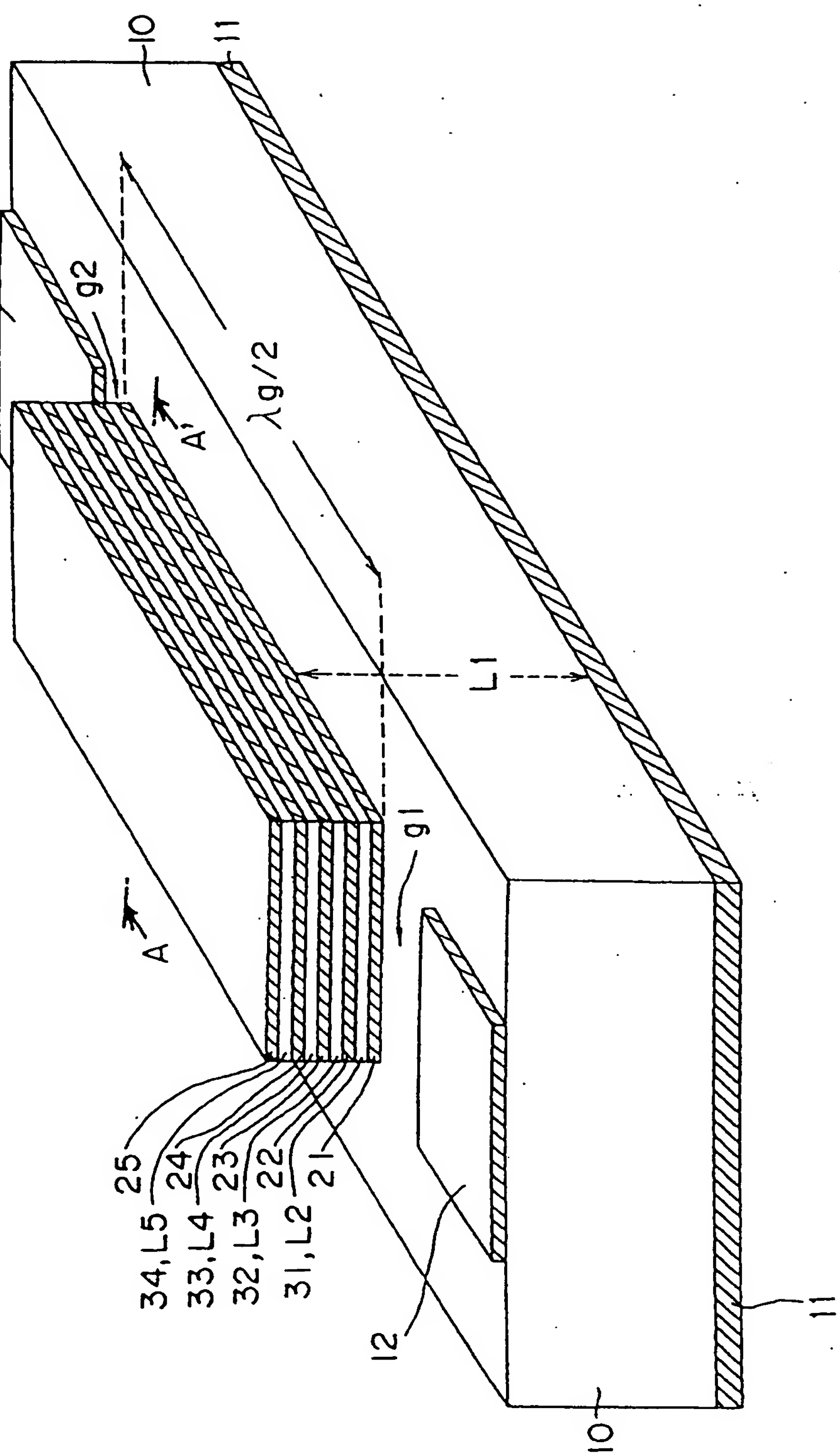


Fig. 2

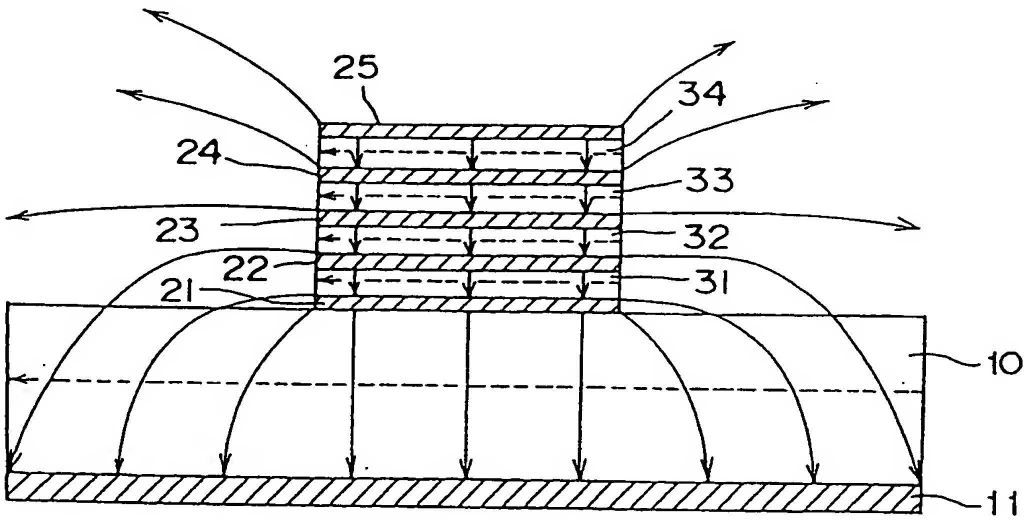
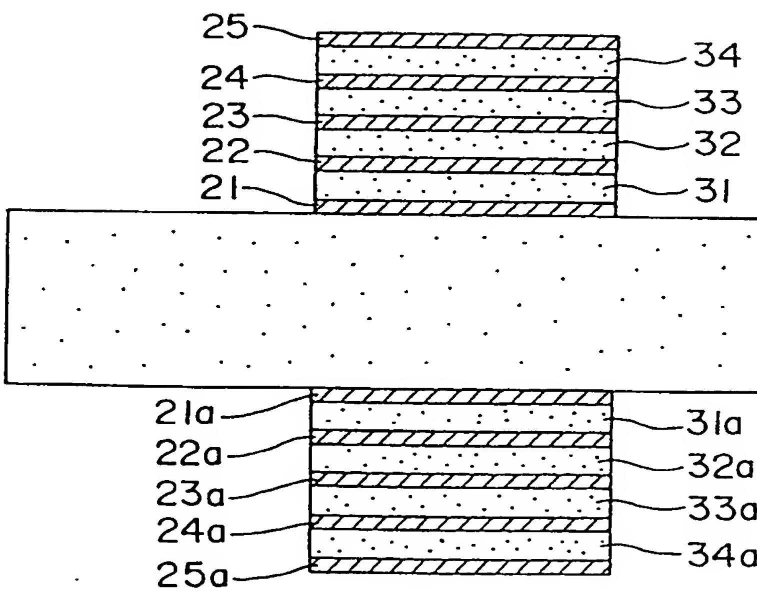

25
34
24
33
23
32
22
31
21
10
11

Fig. 27


25
24
23
22
21
34
33
32
31
10
21a
22a
23a
24a
25a
31a
32a
33a
34a

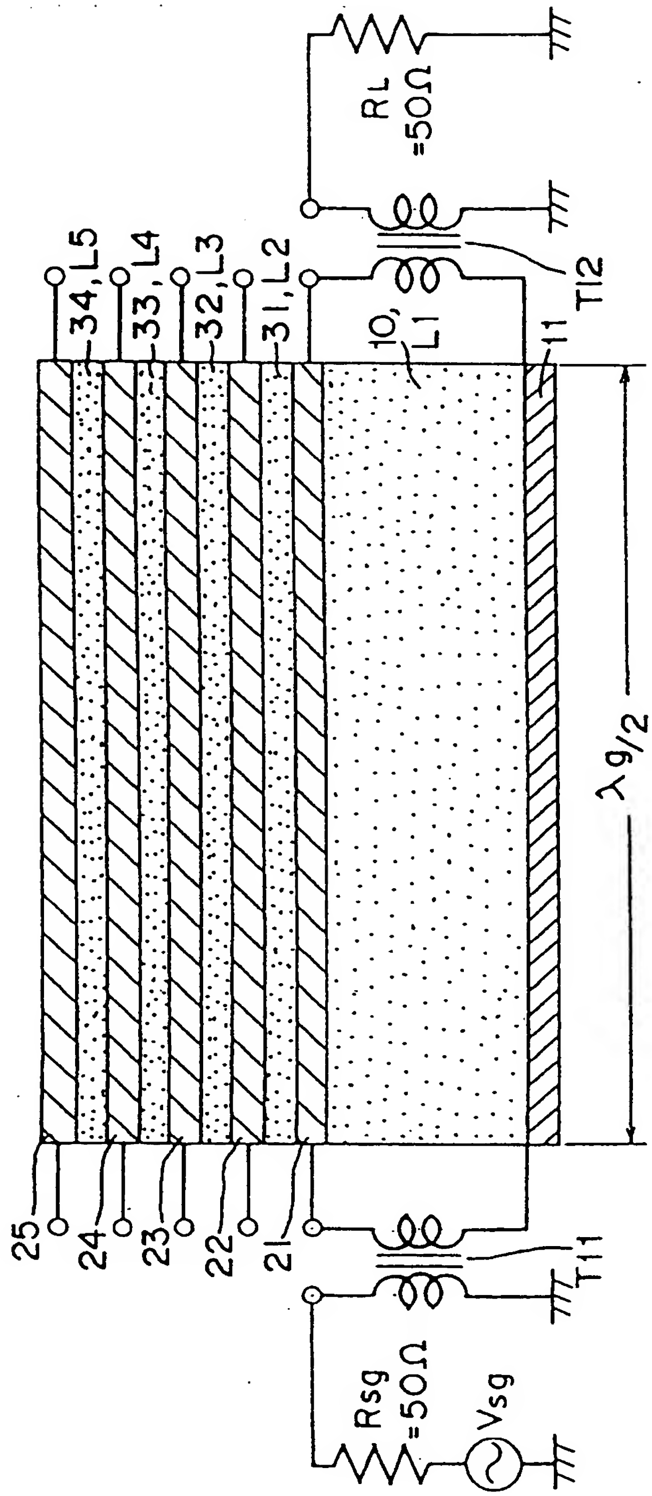

RL
=50Ω
34,L5
33,L4
32,L3
31,L2
10,
L1
11
T12
λg/2
25
24
23
22
21
T11
Rsg
=50Ω
Vsg

Fig. 3

Fig.4

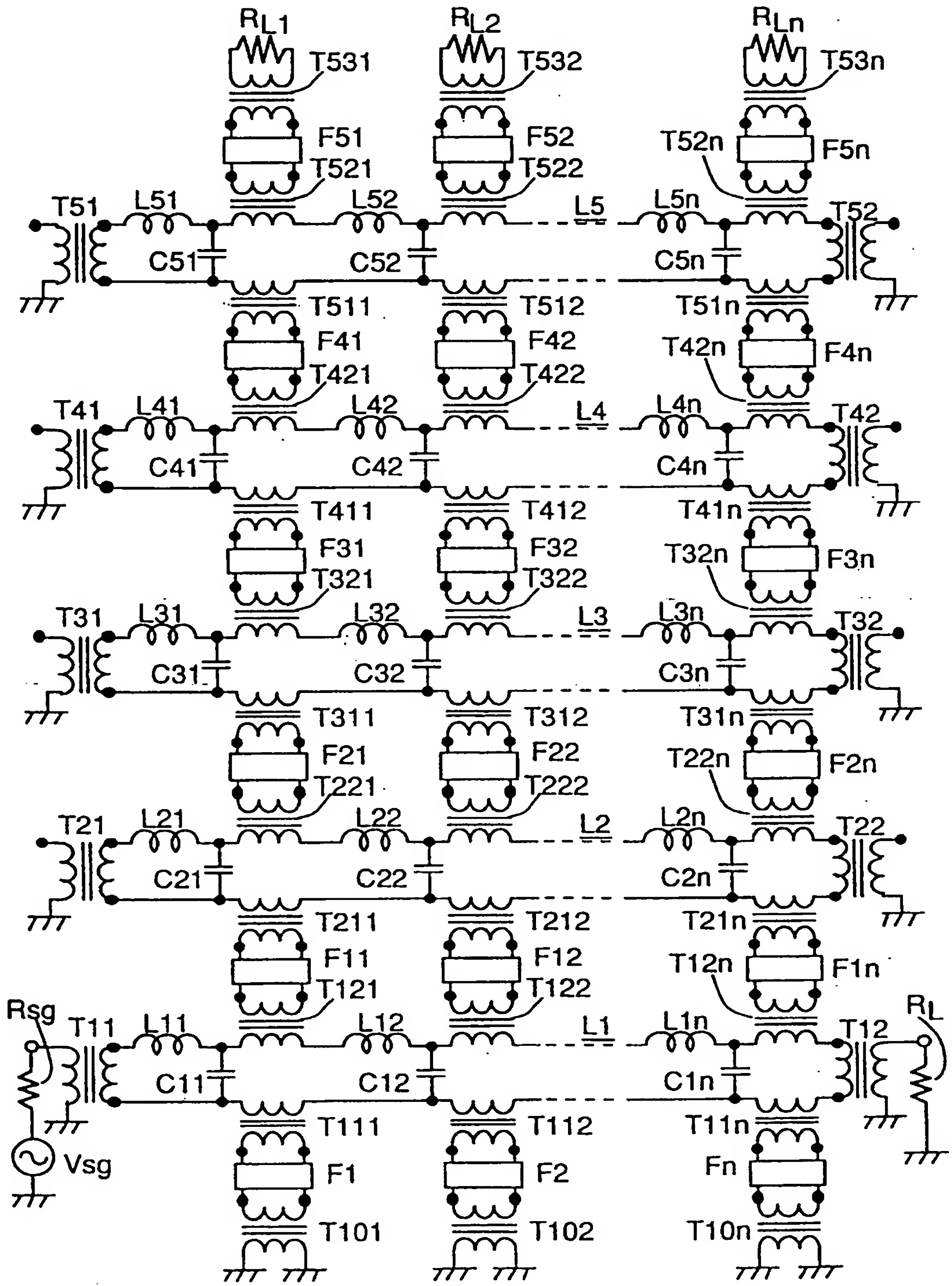
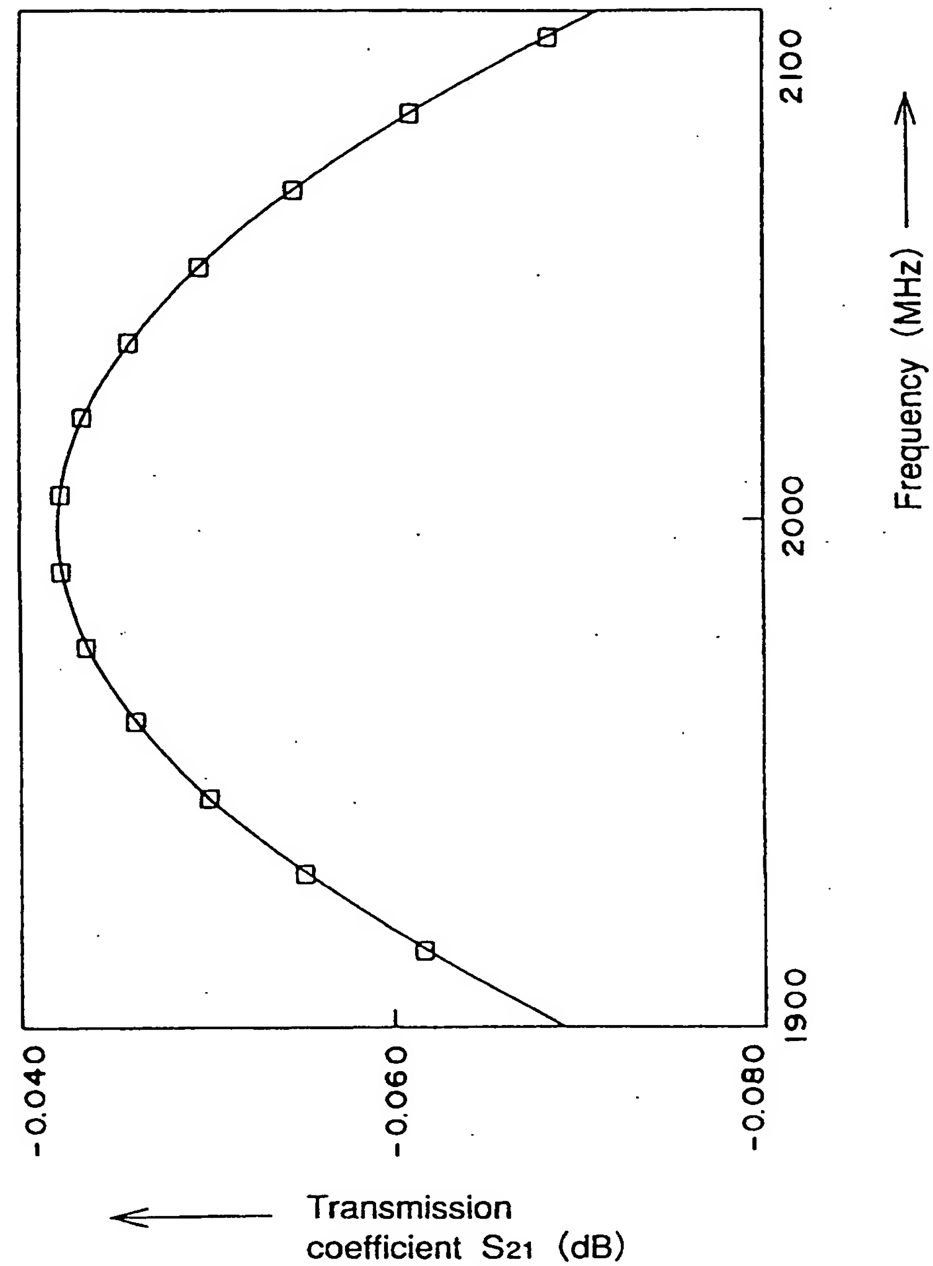

RL1
T531
RL2
T532
RLn
T53n
F51
T521
F52
T522
T52n
F5n
T51
L51
L52
L5
L5n
T52
C51
C52
C5n
T511
T512
T51n
F41
T421
F42
T422
T42n
F4n
T41
L41
L42
L4
L4n
T42
C41
C42
C4n
T411
T412
T41n
F31
T321
F32
T322
T32n
F3n
T31
L31
L32
L3
L3n
T32
C31
C32
C3n
T311
T312
T31n
F21
T221
F22
T222
T22n
F2n
T21
L21
L22
L2
L2n
T22
C21
C22
C2n
T211
T212
T21n
F11
T121
F12
T122
T12n
F1n
Rsg
T11
L11
L12
L1
L1n
T12
RL
C11
C12
C1n
T111
T112
T11n
Vsg
F1
F2
Fn
T101
T102
T10n

Fig. 5


-0.040
-0.060
-0.080
1900
2000
2100
Frequency (MHz)
Transmission
coefficient S21 (dB)

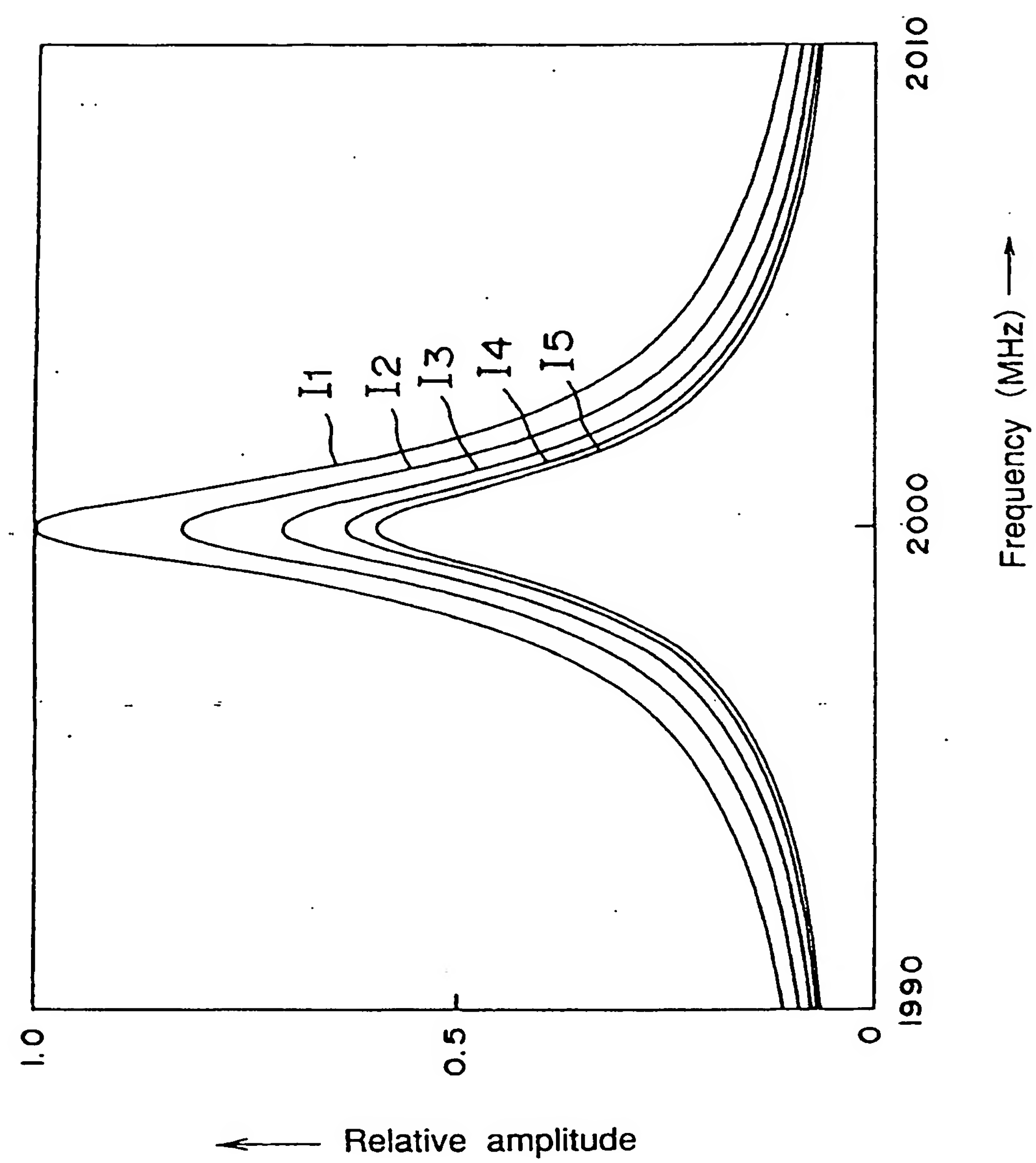

I1
I2
I3
I4
I5
1.0
0.5
0
1990
2000
2010
Frequency (MHz)
Relative amplitude

Fig. 6

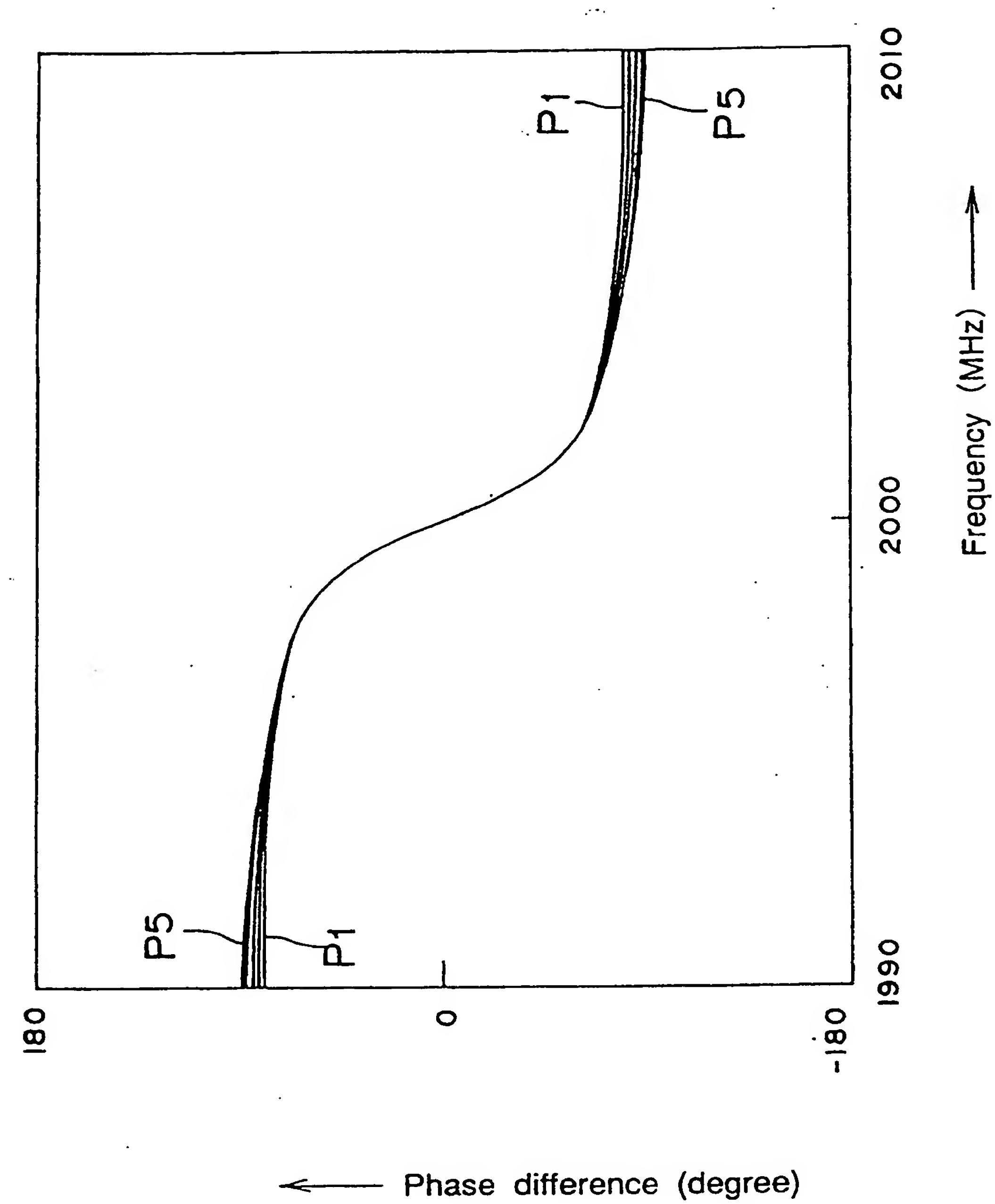

180
0
-180
1990
2000
2010
P5
P1
P1
P5
Frequency (MHz)
Phase difference (degree)

Fig. 7

Fig. 8

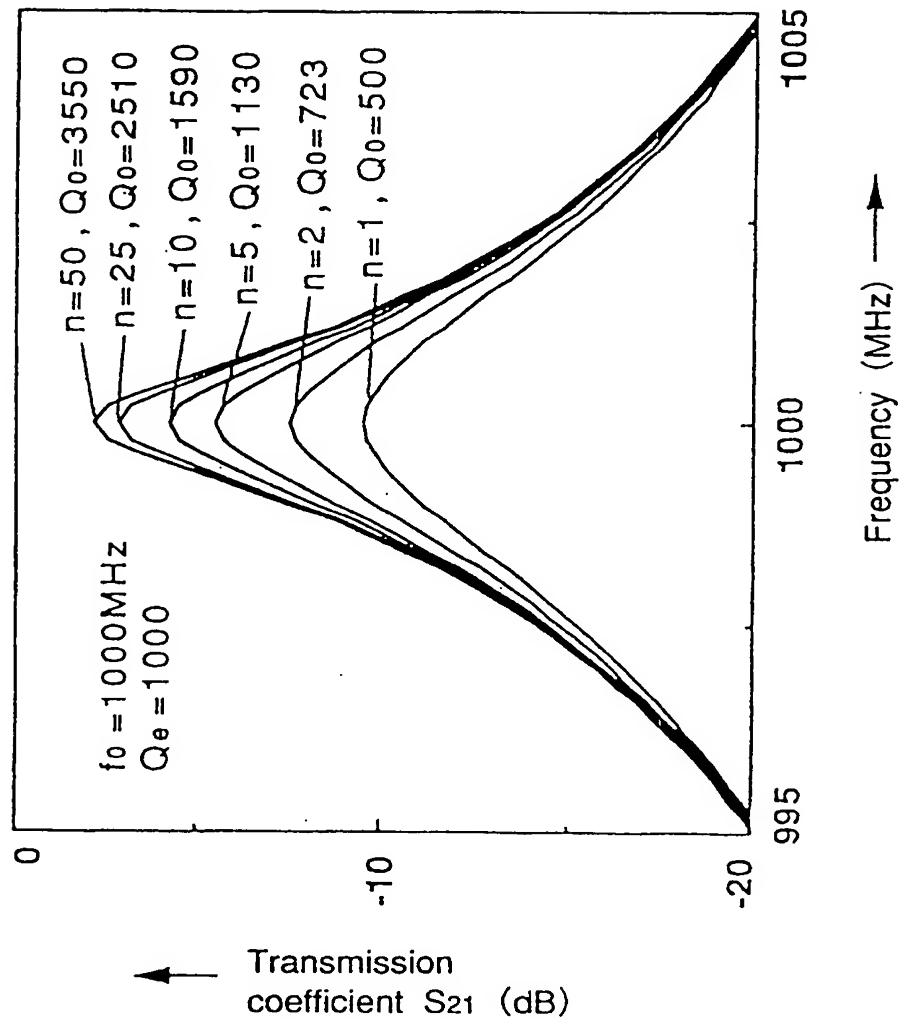

n=50 , Qo=3550
n=25 , Qo=2510
n=10 , Qo=1590
n=5 , Qo=1130
n=2 , Qo=723
n=1 , Qo=500
fo =1000MHz
Qe =1000
0
-10
-20
995
1000
1005
Frequency (MHz)
Transmission
coefficient S21 (dB)

Fig. 9

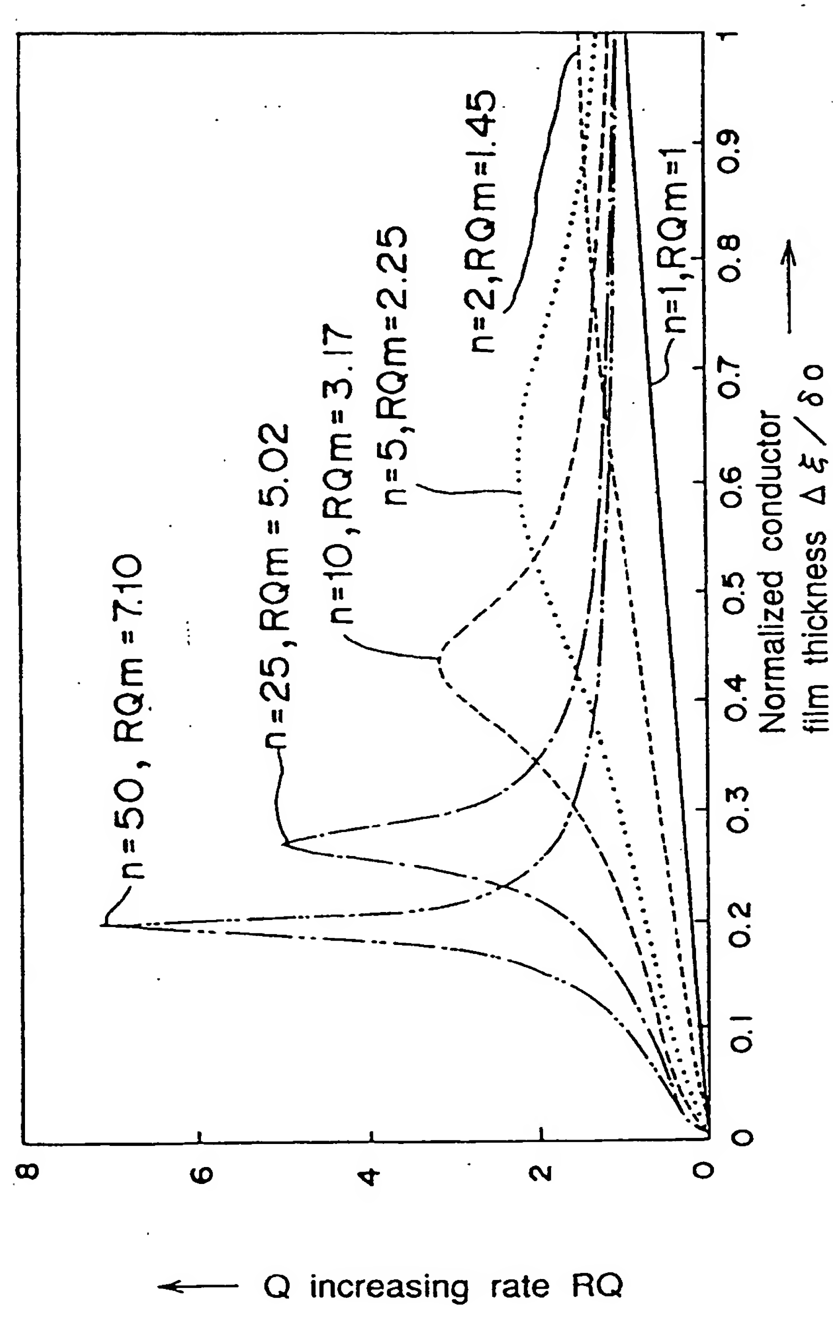

n=50, RQm=7.10
n=25, RQm=5.02
n=10, RQm=3.17
n=5, RQm=2.25
n=2, RQm=1.45
n=1, RQm=1
0
2
4
6
8
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized conductor film thickness $\Delta\xi/\delta o$
Q increasing rate RQ

Fig. 10

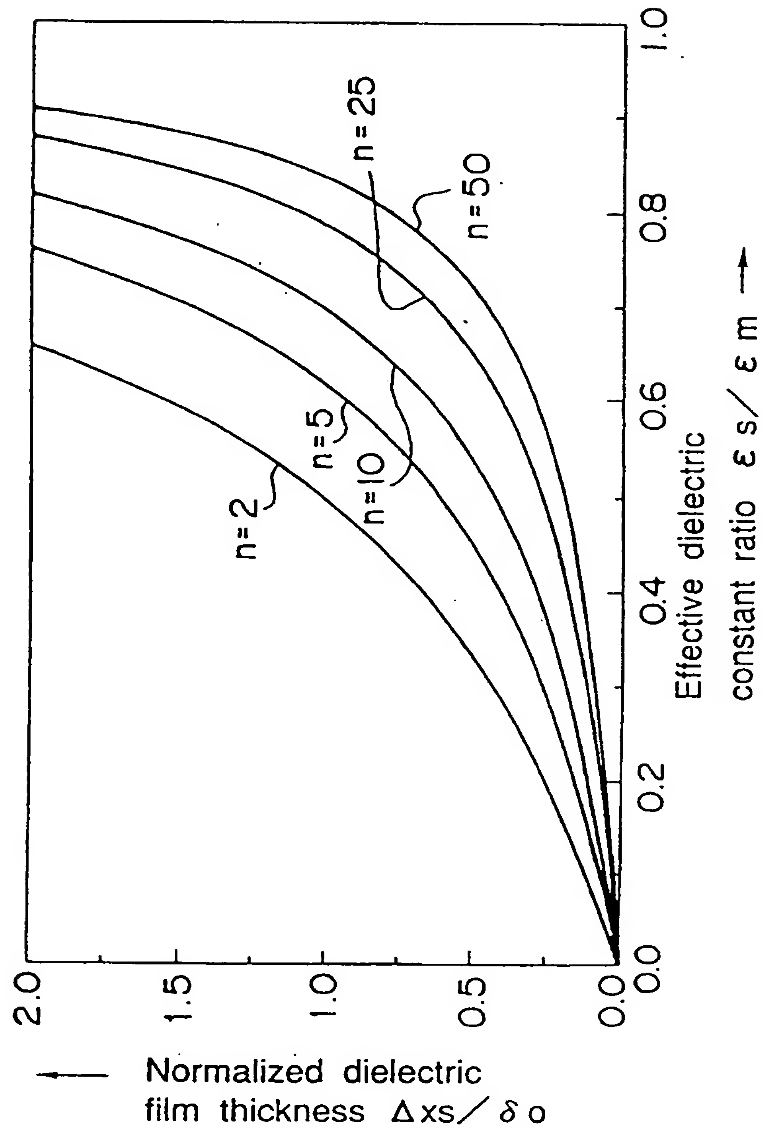

Normalized dielectric film thickness Δxs／δo
Effective dielectric constant ratio εs／εm
n=2
n=5
n=10
n=25
n=50
0.0
0.5
1.0
1.5
2.0
0.0
0.2
0.4
0.6
0.8
1.0

Fig. 11

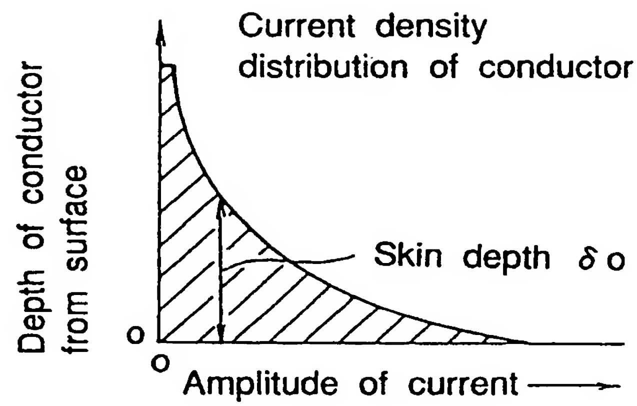


Fig. 12

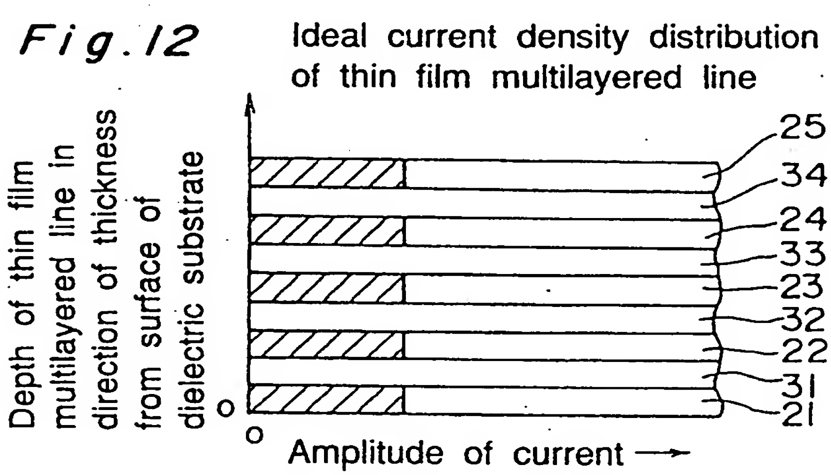


Fig. 13

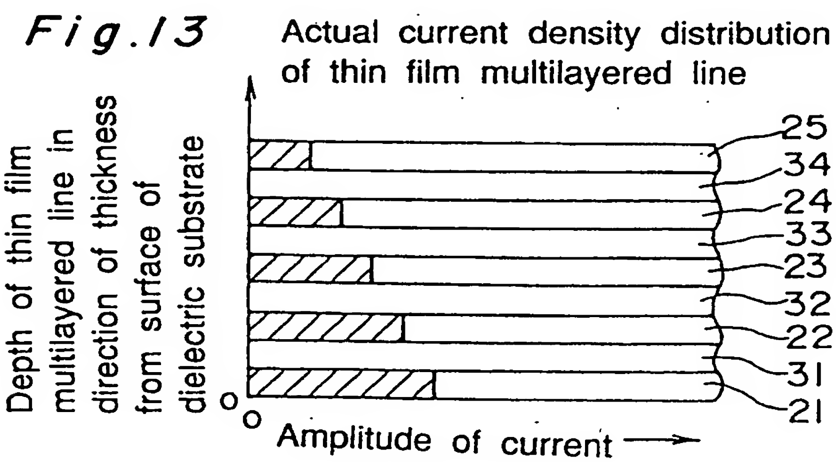


Fig.14

Flow for determining optimum parameters

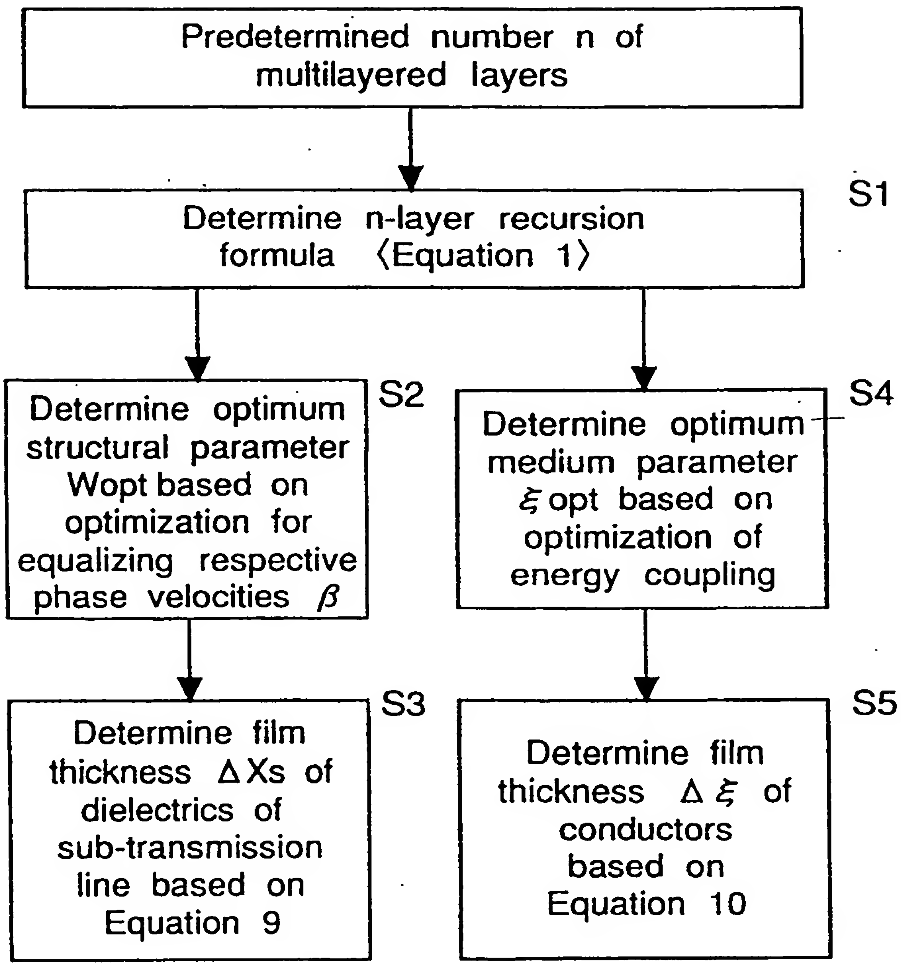


Fig.15

Flow for determining minimized surface resistance

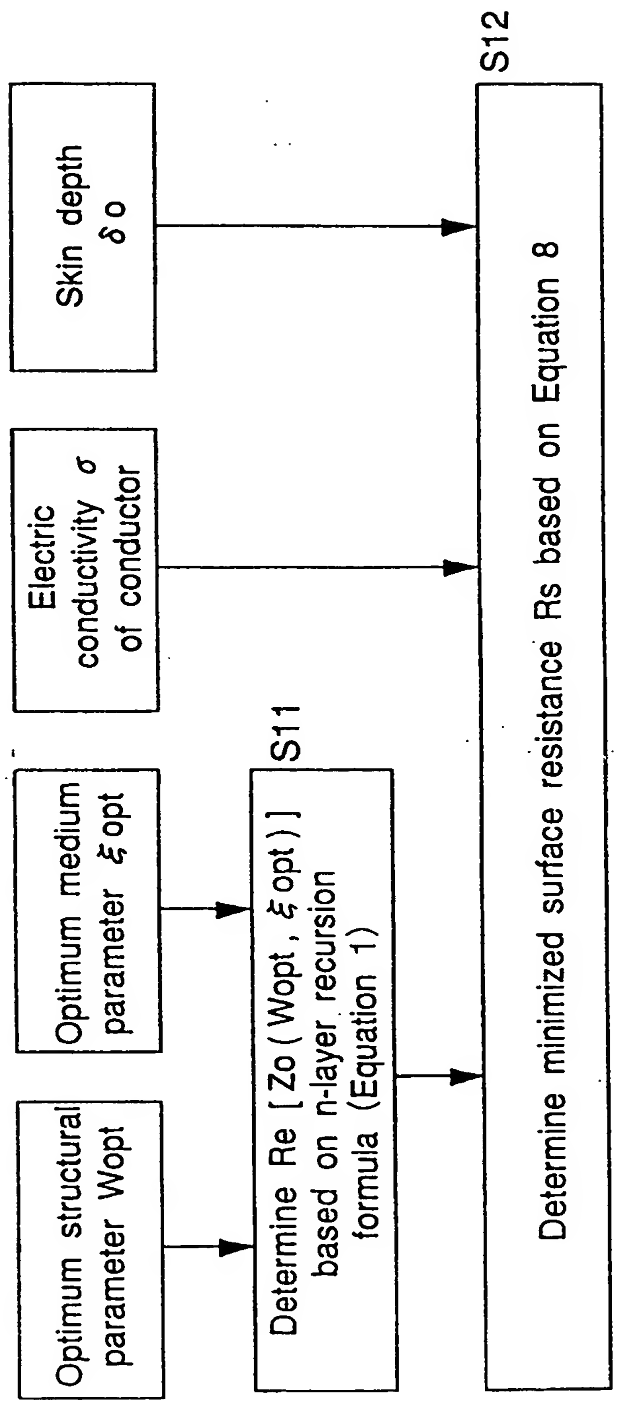


Fig. 16

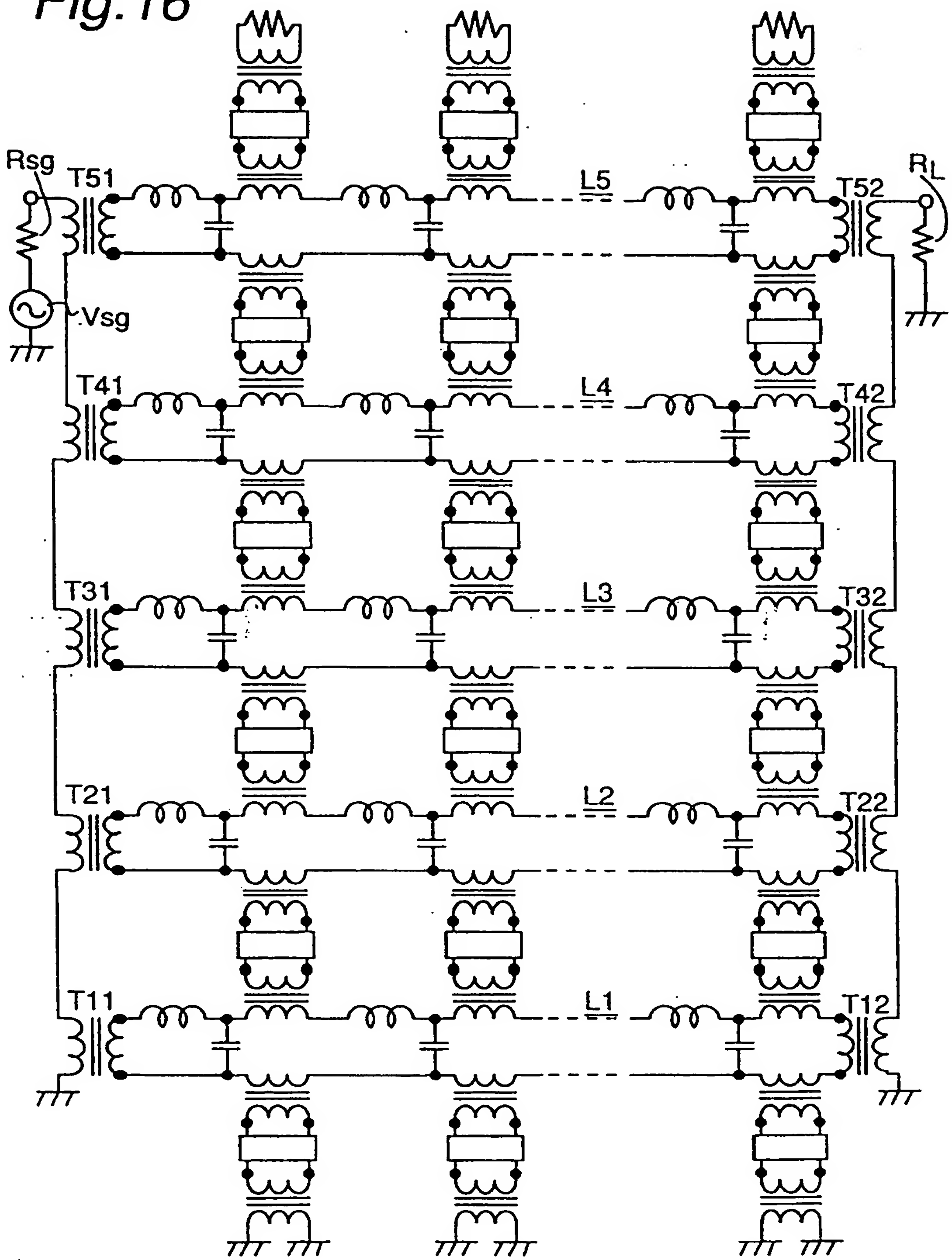


Fig. 17

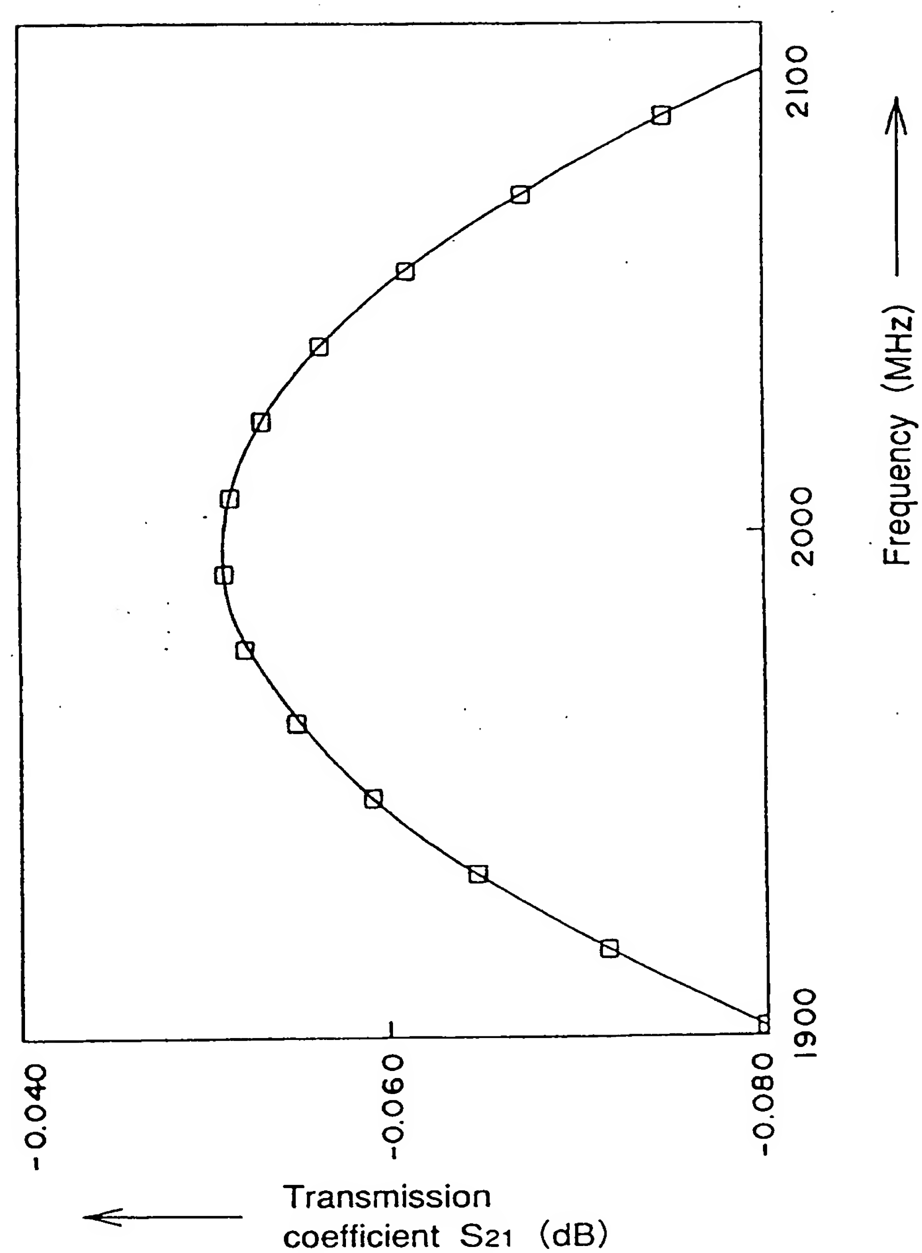

-0.040
-0.060
-0.080
Transmission coefficient S21 (dB)
1900
2000
2100
Frequency (MHz)

Fig. 18

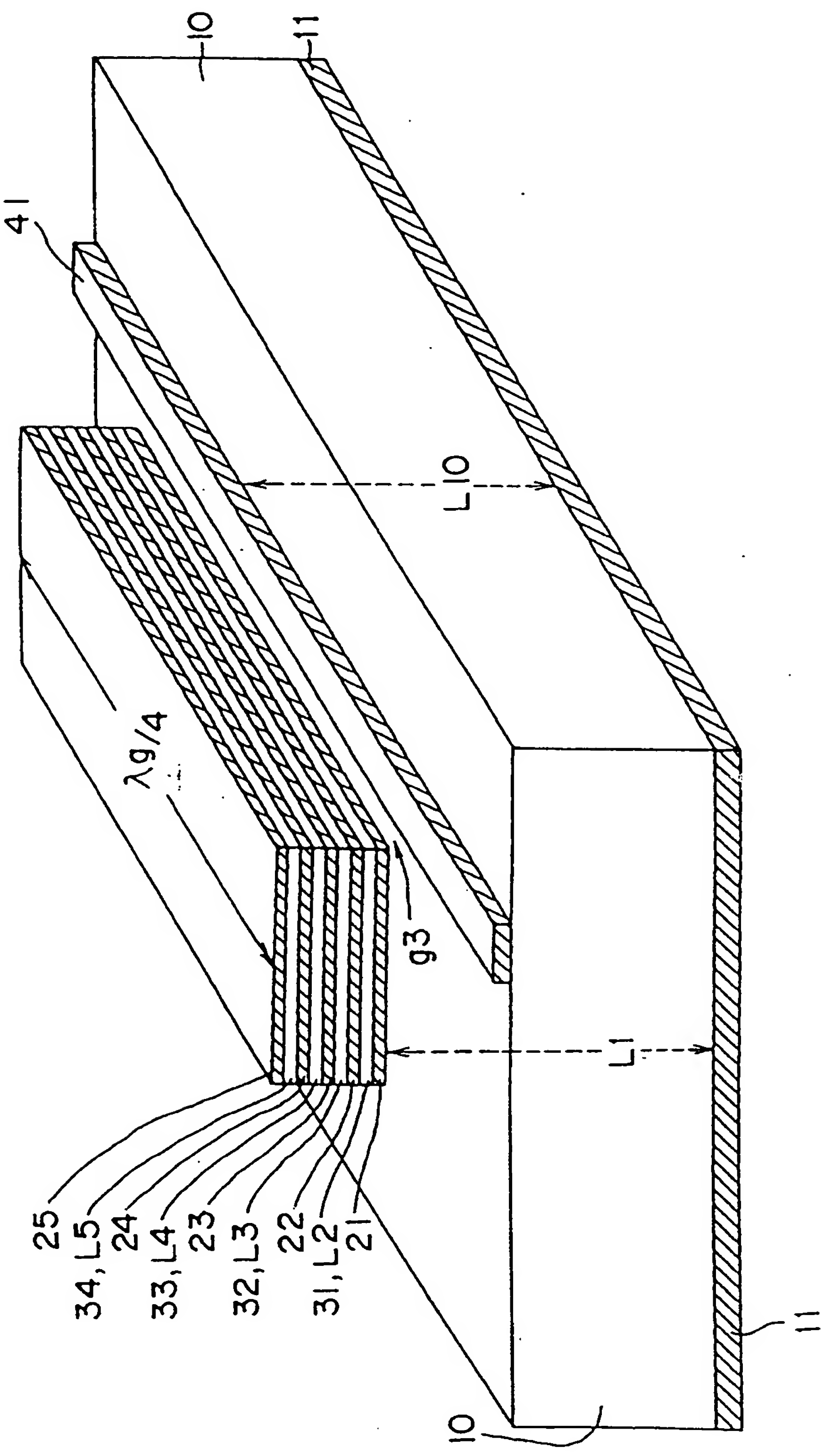


Fig.19

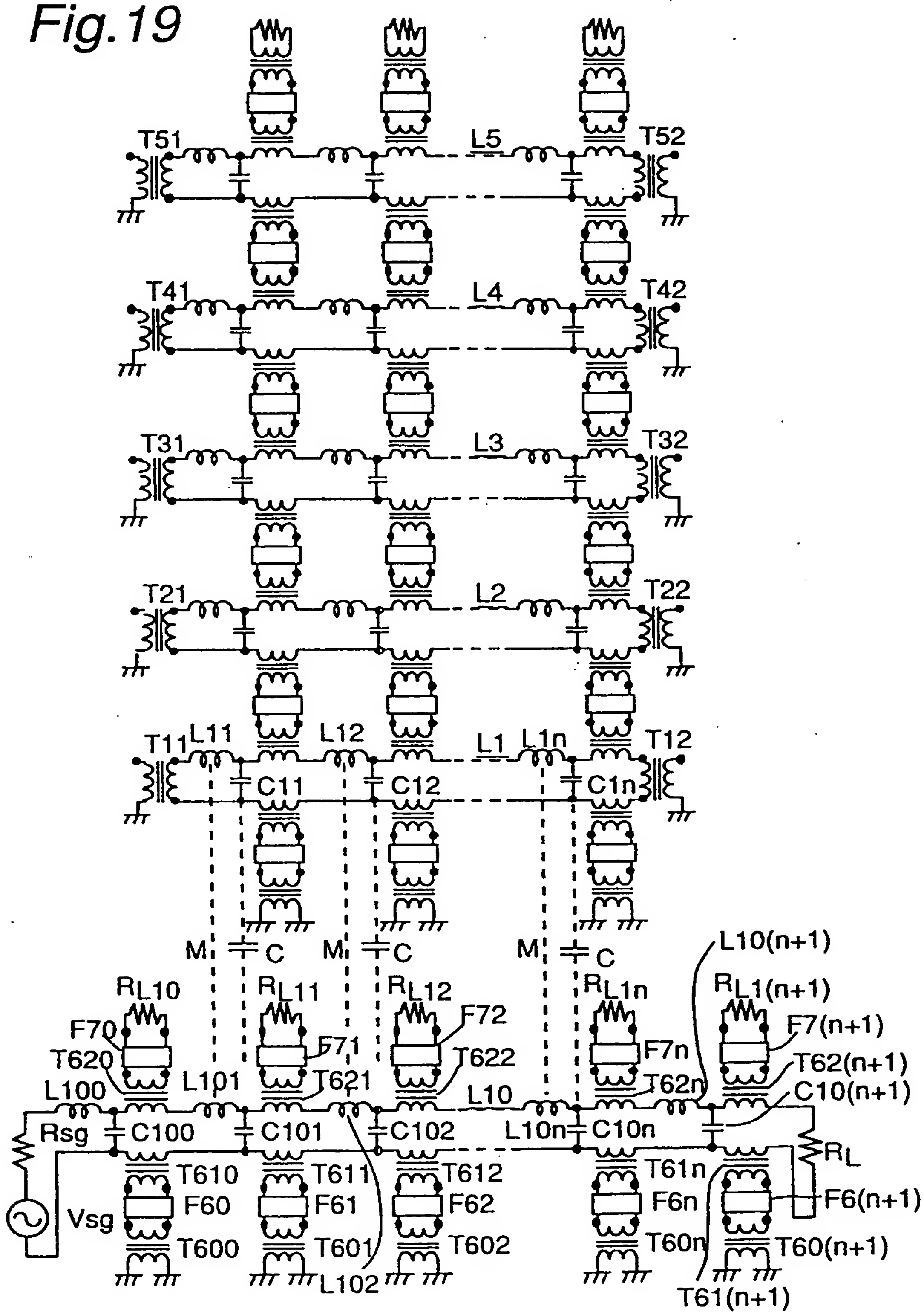

T51
L5
T52
T41
L4
T42
T31
L3
T32
T21
L2
T22
T11
L11
L12
L1
L1n
T12
C11
C12
C1n
M
C
M
C
M
C
L10(n+1)
RL10
RL11
RL12
RL1n
RL1(n+1)
F70
F71
F72
F7n
F7(n+1)
T620
T621
T622
T62n
T62(n+1)
L100
L101
L10
C10(n+1)
Rsg
C100
C101
C102
L10n
C10n
RL
T610
T611
T612
T61n
F60
F61
F62
F6n
F6(n+1)
Vsg
T600
T601
T602
T60n
T60(n+1)
L102
T61(n+1)

Fig. 20

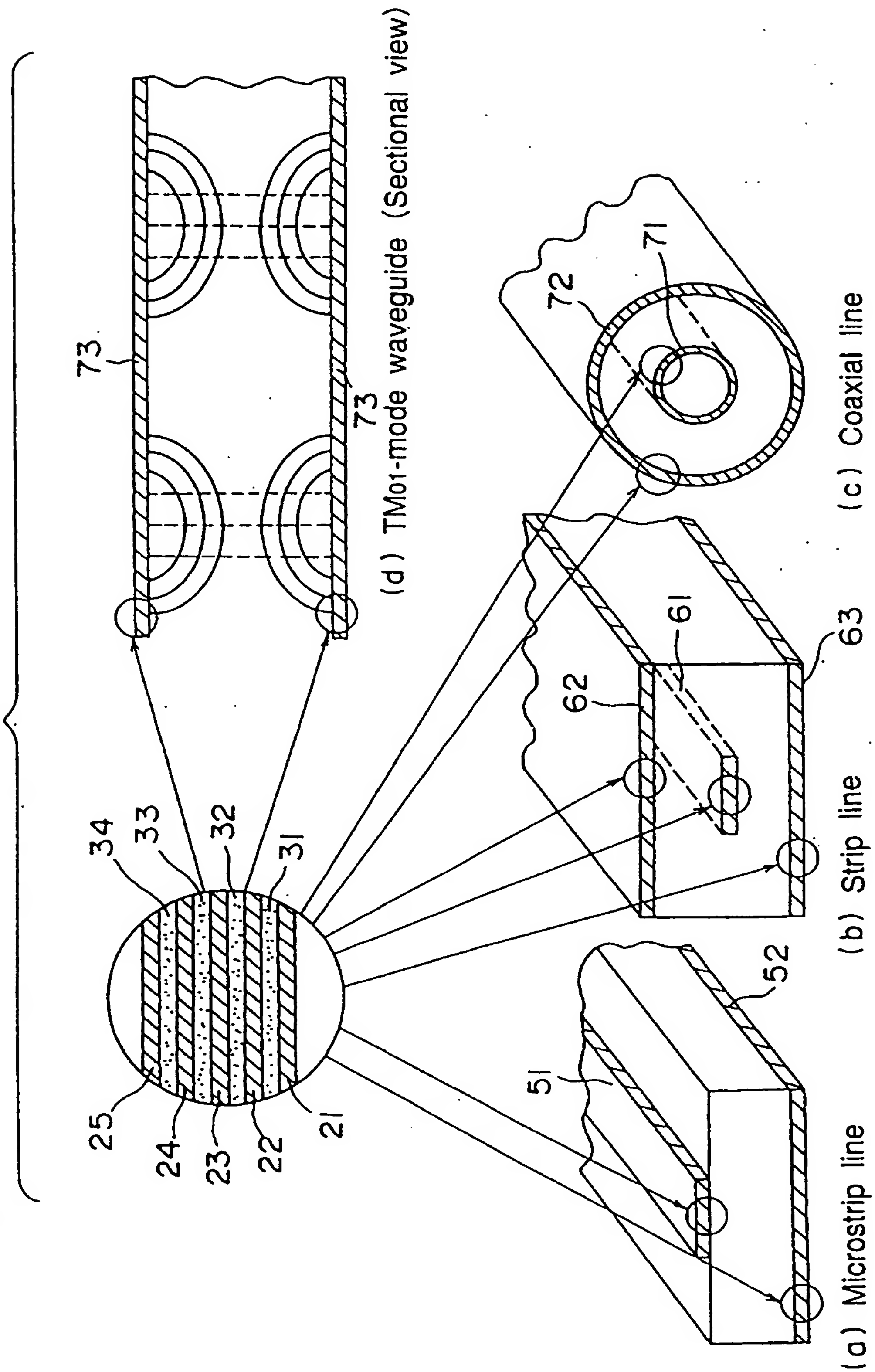

25
24
23
22
21
34
33
32
31
51
52
61
62
63
71
72
73
73
(a) Microstrip line
(b) Strip line
(c) Coaxial line
(d) TM01-mode waveguide (Sectional view)

Fig. 21

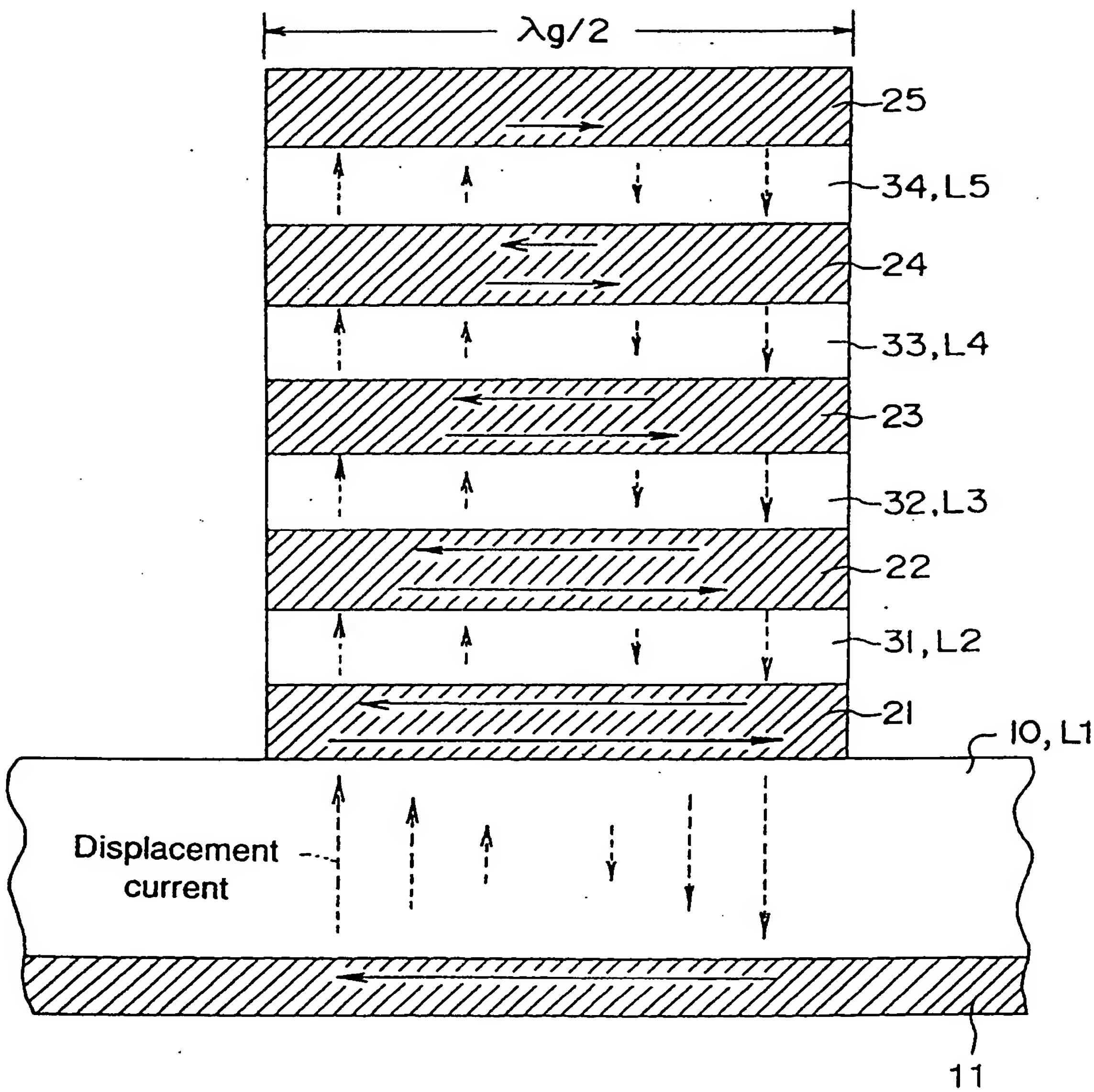

λg/2
25
34, L5
24
33, L4
23
32, L3
22
31, L2
21
10, L1
Displacement
current
11

Fig. 22

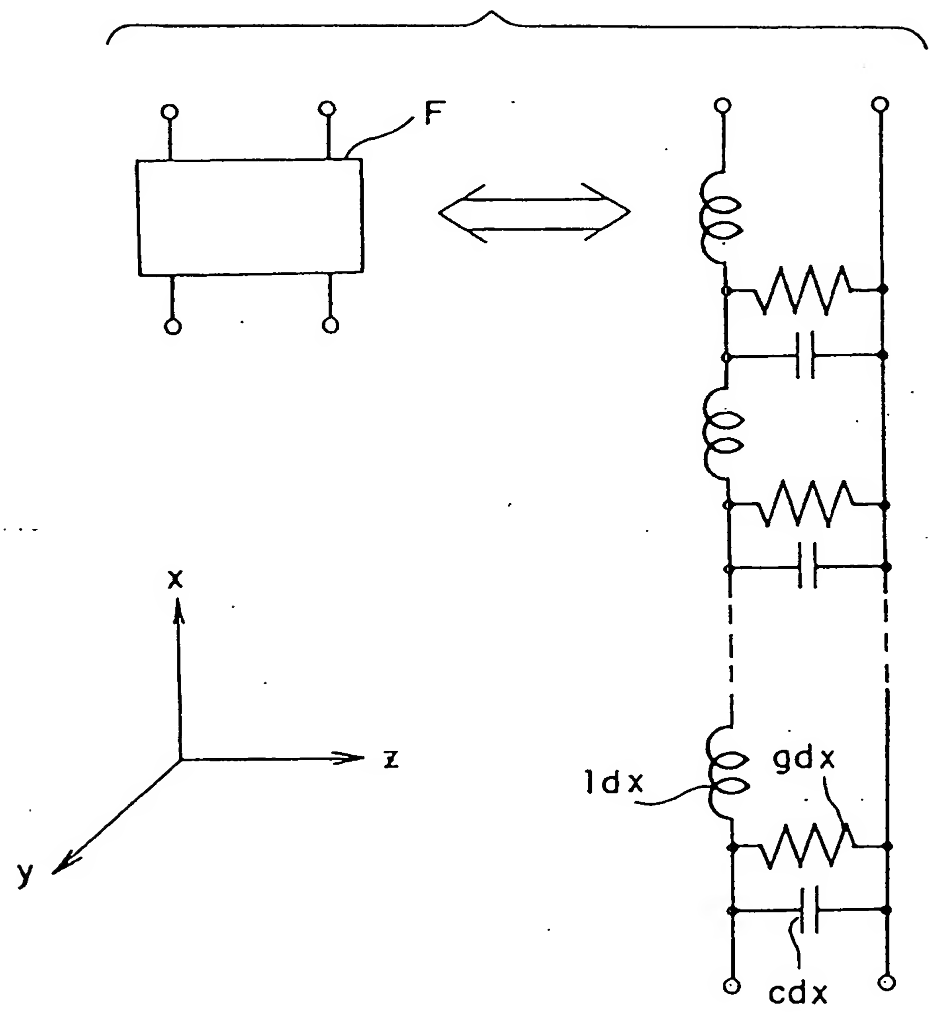
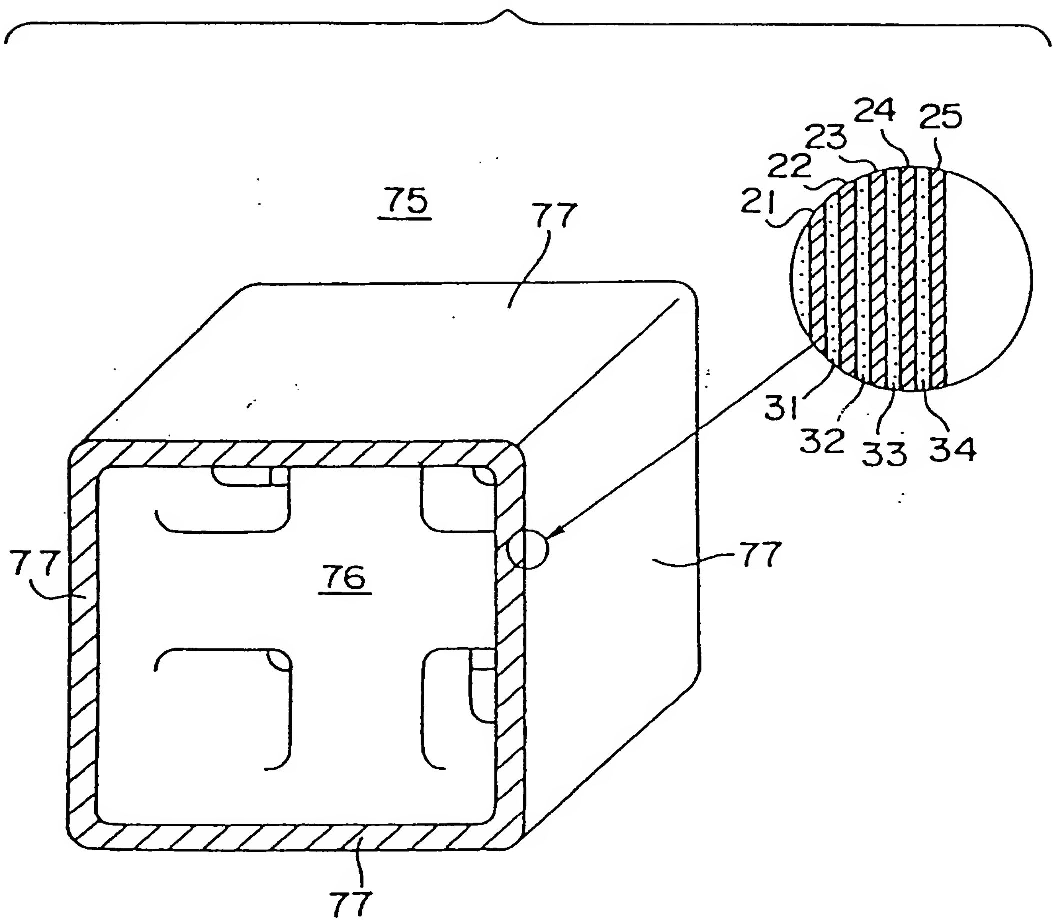


Fig. 23



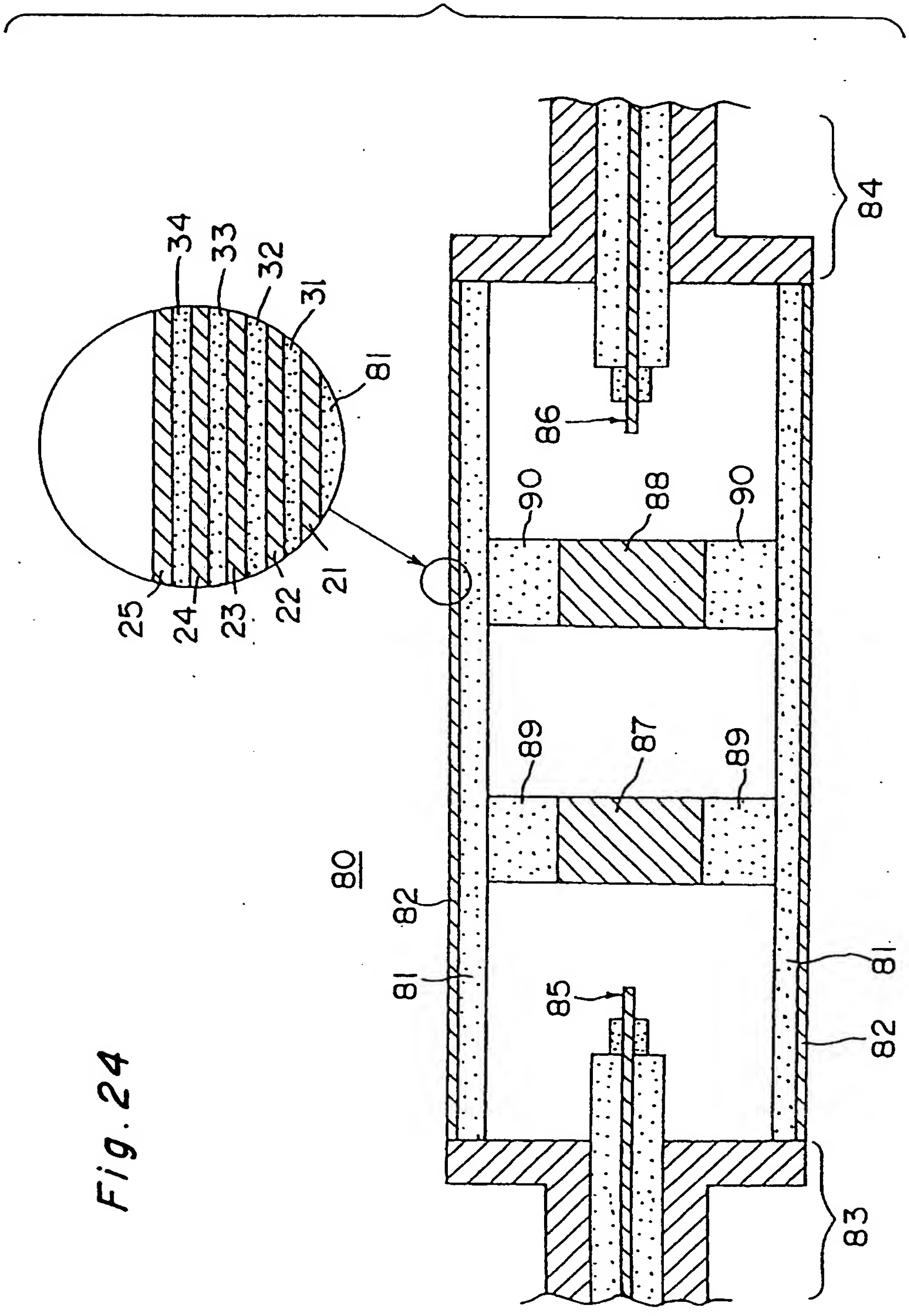
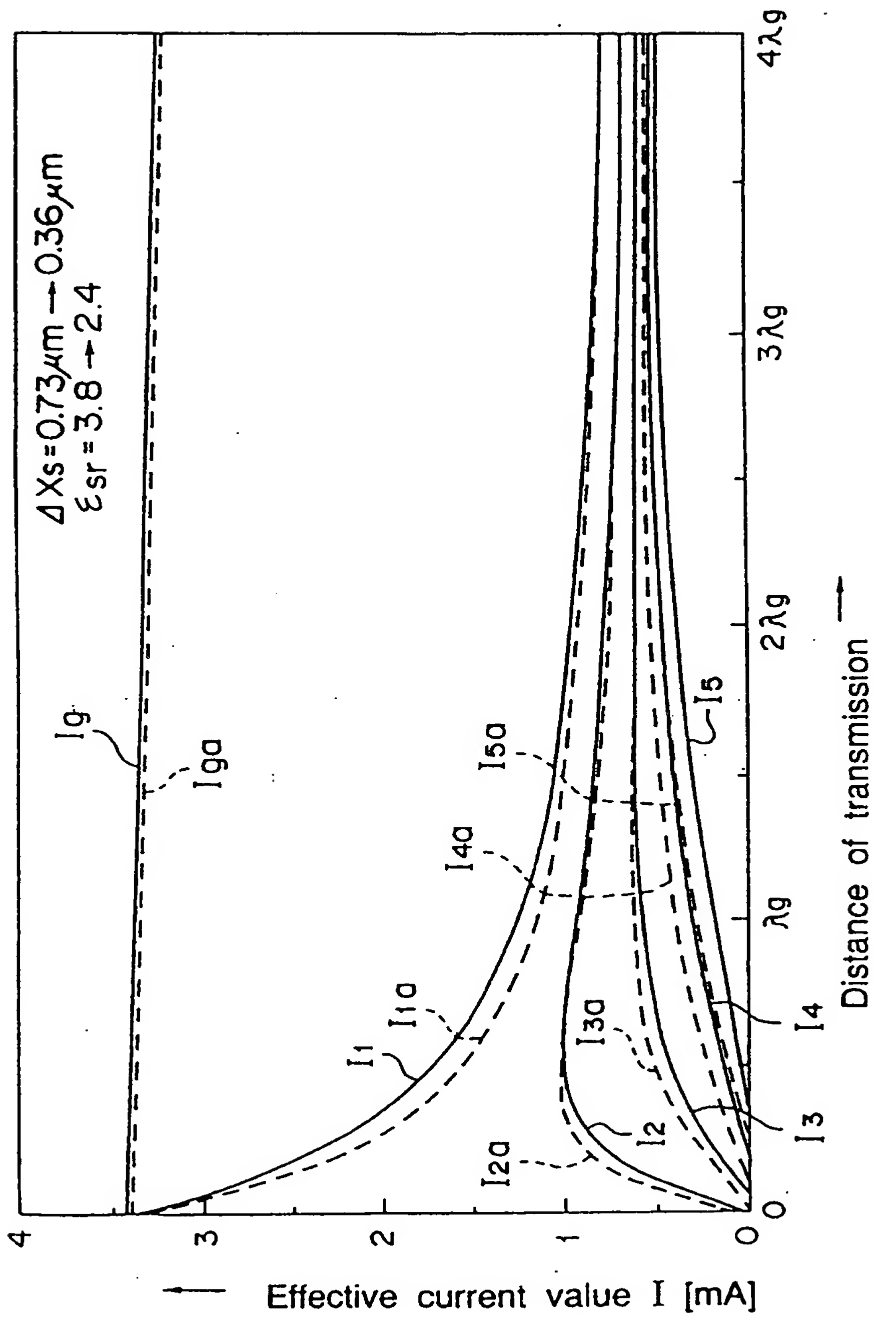

34
33
32
31
81
25
24
23
22
21
86
90
88
90
89
87
89
80
82
81
85
81
82
84
83

Fig. 24

Fig. 25



ΔXs=0.73μm → 0.36μm
εsr = 3.8 → 2.4
Ig
Iga
I1
I1a
I2
I2a
I3
I3a
I4
I4a
I5
I5a
0
1
2
3
4
λg
2λg
3λg
4λg
← Effective current value I [mA]
Distance of transmission →

Fig. 26

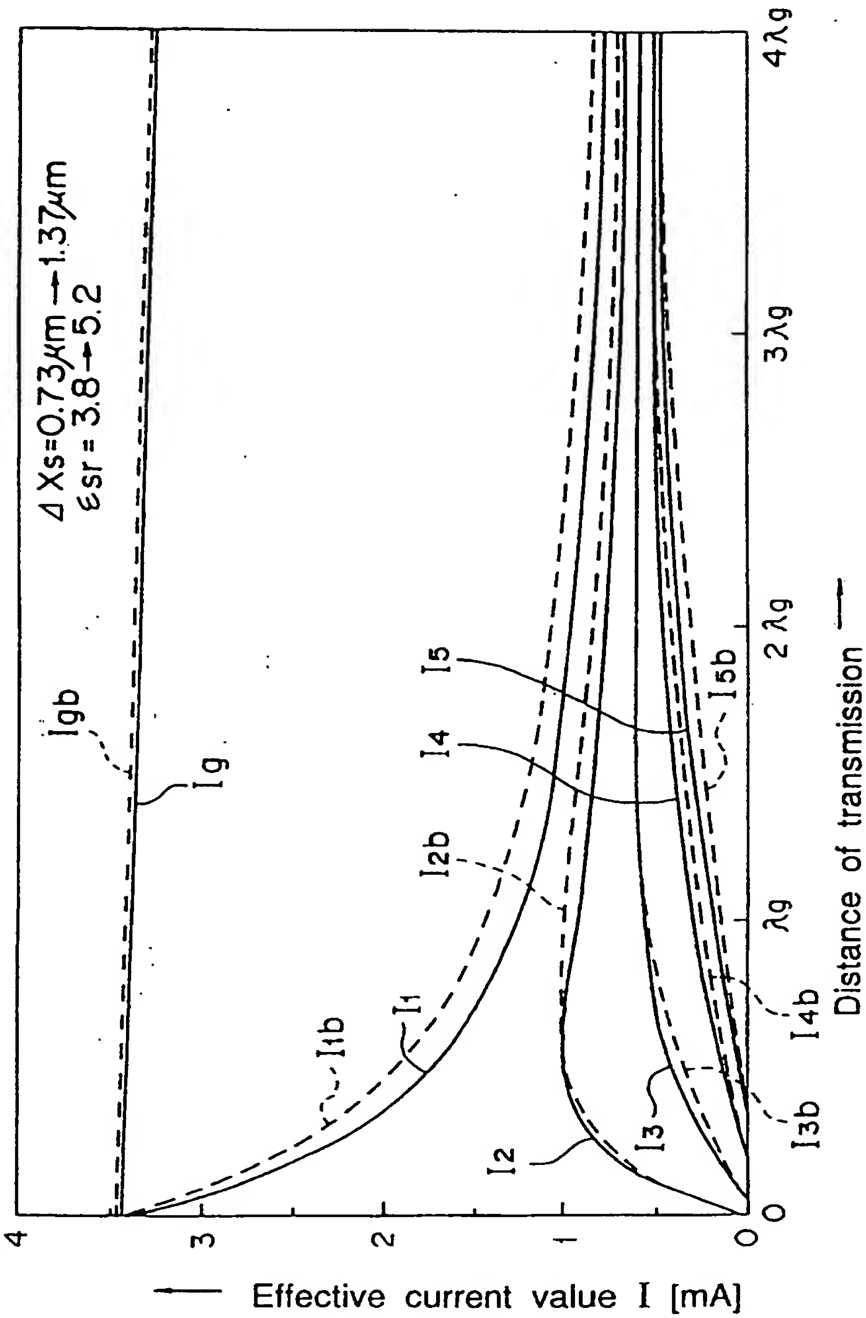
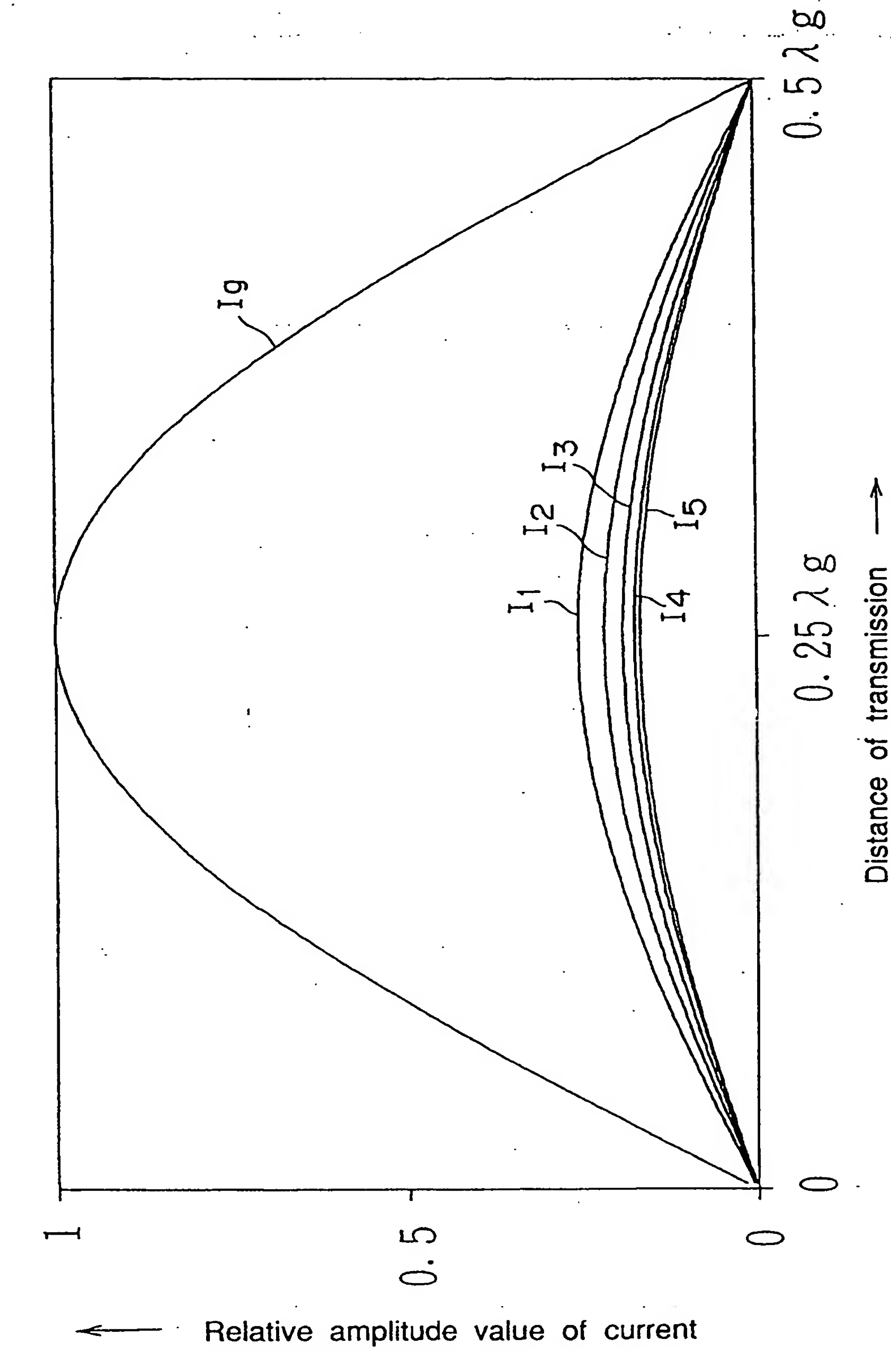

ΔXs=0.73μm→1.37μm
εsr = 3.8→5.2
Igb
Ig
I1b
I1
I2b
I2
I3
I3b
I4
I4b
I5
I5b
0
1
2
3
4
λg
2λg
3λg
4λg
Effective current value I [mA]
Distance of transmission

Fig.28


Ig
I1
I2
I3
I4
I5
0
0.25λg
0.5λg
Distance of transmission →
1
0.5
0
← Relative amplitude value of current

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP94/00357

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl^5 H01P3/18, H01P3/06, H01P3/08, H01P3/12, H01P7/08, H01P1/203, H01P1/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl^5 H01P3/18, H01P3/06, H01P3/08, H01P3/12, H01P7/08, H01P1/203, H01P1/20

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1950 - 1994
Kokai Jitsuyo Shinan Koho 1971 - 1994

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, WPI/L

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, B, 28-3635 (Western Electric Co., Inc.), July 31, 1953 (31. 07. 53), Full descriptions, all drawings, (Family: none)	1-21
Y	JP, B, 30-1787 (Western Electric Co., Inc.), March 18, 1955 (18. 03. 55) Full descriptions, all drawings, (Family: none)	1-21
Y	JP, B, 30-4632 (Western Electric Co., Inc.), July 7, 1955 (07. 07. 55), Full descriptions, all drawings, (Family: none)	1-21
Y	JP, A, 51-138881 (Nippon Telegraph & Telephone Public Corp.), November 30, 1976 (30. 11. 76), Full descriptions, all drawings, (Family: none)	1-21
Y	JP, A, 4-43703 (NGK Insulators, Ltd.), February 13, 1992 (13. 02. 92), Full descriptions, all drawings, (Family: none)	1-21

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
June 2, 1994 (02. 06. 94)	June 28, 1994 (28. 06. 94)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)